Vol. XXI. — No. 8. August 1939.

BULLETIN
OF THE
INTERNATIONAL RAILWAY CONGRESS
ASSOCIATION
(ENGLISH EDITION)

[621. 335 (.494) & 621. 338 (.494)]

Light-weight electric trains,

classes BCFZe 4/6 and CFZe 2/6, of the Bernese Alps Railway Company (BERN - LOETSCHBERG - SIMPLON)

by L. LEYVRAZ, Chief Mechanical Engineer.

In the latter half of the year 1935 the Bernese Alps Railway Company (B.L.S.) put into service five light-weight motor coaches, class Ce 2/4, in order to reduce the dead weight of trains on branch lines and at the same time to effect certain savings in operating costs. These light-weight coaches have been described in the technical press (1). They were not constructed for solo running on the lines to which they were assigned, for it had been foreseen that in certain circumstances they would have to be capable of hauling trailing loads up to 40 tons gross.

Immediately after their entry into service, operating requirements showed that several trains in which these coaches ran would have to be formed thus : (1) — light-weight motor coach; (2) — 2nd and 3rd class composite trailer; (3) — luggage and mail van. However, on account of motor heating, a train of this formation, of about 35 tons trailing load and 75 tons total load (of which about 40 tons were due to the gross weight of the motor coach) could only operate on lines with gradients not exceeding 1 in 50 to 1 in 45, e. g., the Berne-Neuchâtel line (B. N. through line) and that between Berne and Thoune through the Gürbe Valley (G. T. B.).

It was therefore necessary to produce a light-weight motor coach powerful enough to haul these loads even on the 1 in 40 and 1 in 37 gradients of the Spiez-Zweisimmen (S. E. B./E. Z. B.) and Spiez-Brigue (B. L. S.) lines, which should at the same time have a passenger-carrying capacity which would render the addition of trailers unnecessary, or at least confine such additions to certain exceptional cases of abnormal numbers of passengers.

The final arrangement, which was extremely simple, was to couple together two motor coaches of the Ce 2/4 type, similar to those constructed at the Sé-

(1) *Bulletin of the International Railway Congress Association*, December 1937, p. 2255.
Gewichtsersparnis im Transportwesen, October 1936.
Traction électrique, October 1937.

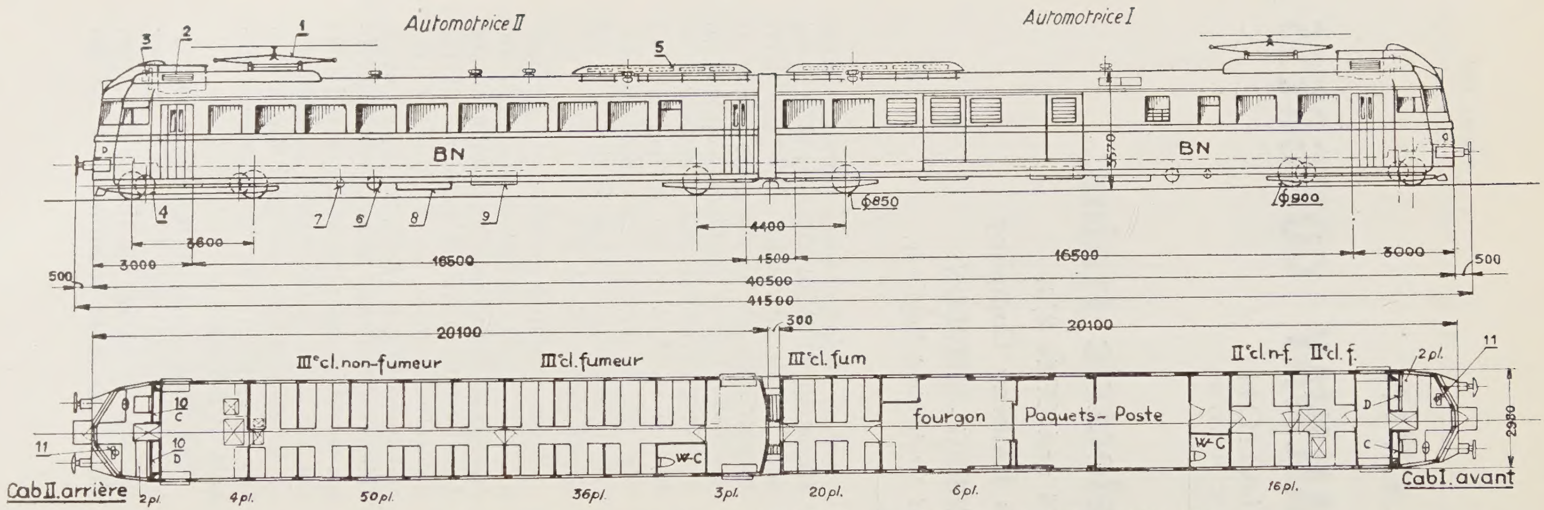


Fig. 1. — Dimensions diagram for the BLS/BN, type BCFZe 4/6, light-weight train.

Chief particulars:

Single-phase current	15 000 V., 16 2/3 cycles
Standard gauge	1.435 m. (4 ft. 8 1/2 in.)
Number of light-weight trains	3

Transformer mounted in the roof.
Four motors with spring and cup transmission.
Rheostatic braking.
Mechano-pneumatic contactor control.
22 running notches, 18 braking notches.
SIG mechanical portion.

Power at wheel tread:	
Hourly rating (at 76 km. = 47.2 miles) p.h.	920 H.P.
Continuous (at 81 km. = 50.3 miles) p.h.	832 H.P.
Tractive effort at wheel tread:	
Hourly rating	3 260 kgr. (*7 200 lb.*)
Continuous	2 780 kgr. (*6 100 lb.*)
Maximum	6 000 kgr. (*13 200 lb.*)
Maximum hourly speed . . .	110 km. (*68.3 m.*)
Driving wheel diameter . . .	900 mm. (*2' 11 1/2"*)
Gear ratio	1 : 3.5

Weight of electrical portion .	20.0 t.
Weight of mechanical portion	47.5 t.
Service equipment	0.5 t.
Weight in working order . .	68.0 t. (*or 66.9 Engl. tons*)
Load	17.0 t.
Maximum total weight . . .	85.0 t. (*or 83.7 Engl. tons*)
Number of seats (including tip-up seats)	139
Standing places	41
Total passenger accommodation	180

Key to items of equipment:

1. Pantograph current collector.
2. Stepped transformer.
3. Mechano-pneumatic control contactors.
4. Traction motor.
5. Braking resistance.
6. Motor-compressor.
7. Motor-generator.
8. Battery of accumulators.
9. Traction motor shunt.
10. Distribution panels.

C. Relay panel.
D. Direct-current distribution panel.
11. Coupling and reversing switch.

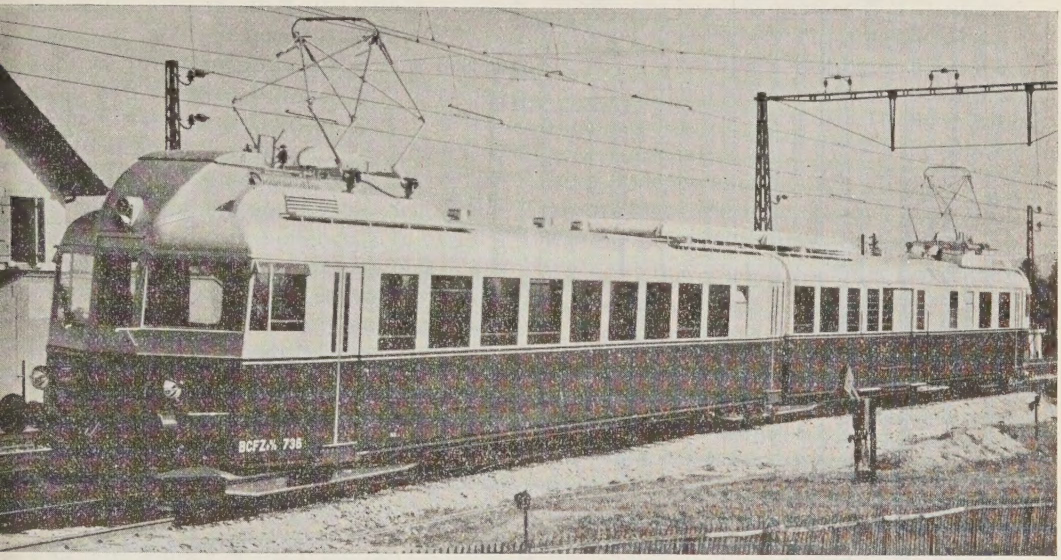


Fig. 2. — Light-weight train BCFZe 4/6 736 in Versoix station.

cheron Works and Swiss Locomotive Works at Winterthur (see articles mentioned above), and so to form a *two-coach light-weight train unit.*

This train, class BCFZe 4/6 (figs. 1 and 2), is therefore composed of one all-third-class coach and another coach, close-coupled, comprising four different compartments, viz : a third-class compartment forming a continuation of those in the first coach; next, a luggage van with a cell for prisoners; then a mail compartment with parcels and letter sections; and finally a second-class compartment.

Entrance vestibules are located at each end of the first coach : a third vestibule is arranged next to the second-class compartment. Finally, at each end of the train are the driver's cabins, which are provided with all the levers and switches necessary for the operation of the train. Each cabin also contains two seats, one second and one third class. These seats are greatly in demand, since from them an uninterrupted view of the track and countryside in front of the coach is obtainable.

As is shown in Fig. 1, the BCFZe 4/6 light train has a total length over buffers of 41.50 m. (136 ft. 2 in.) : each body is 20.25 m. (66 ft. 5 in.) long. The entries at the ends of the coaches have lengths of 2.45 m. (8 ft. 1/2 in.), 1.82 m., (5 ft. 11 21/32 in.), and 0.925 m. (3 ft. 7/16 in.) respectively.

The two coaches are carried on three bogies, the two end ones being motor bogies; the middle one is a trailer only. The total wheelbase is 38.10 m. (125 ft.).

In the case of the *Berne-Schwarzenburg* line (B. S. B.) which is of a more winding character with steeper gradients, but carries less traffic than the other lines, the B. L. S. Company was faced with a similar situation to that described above, viz : the fairly frequent necessity of attaching to the light-weight motor

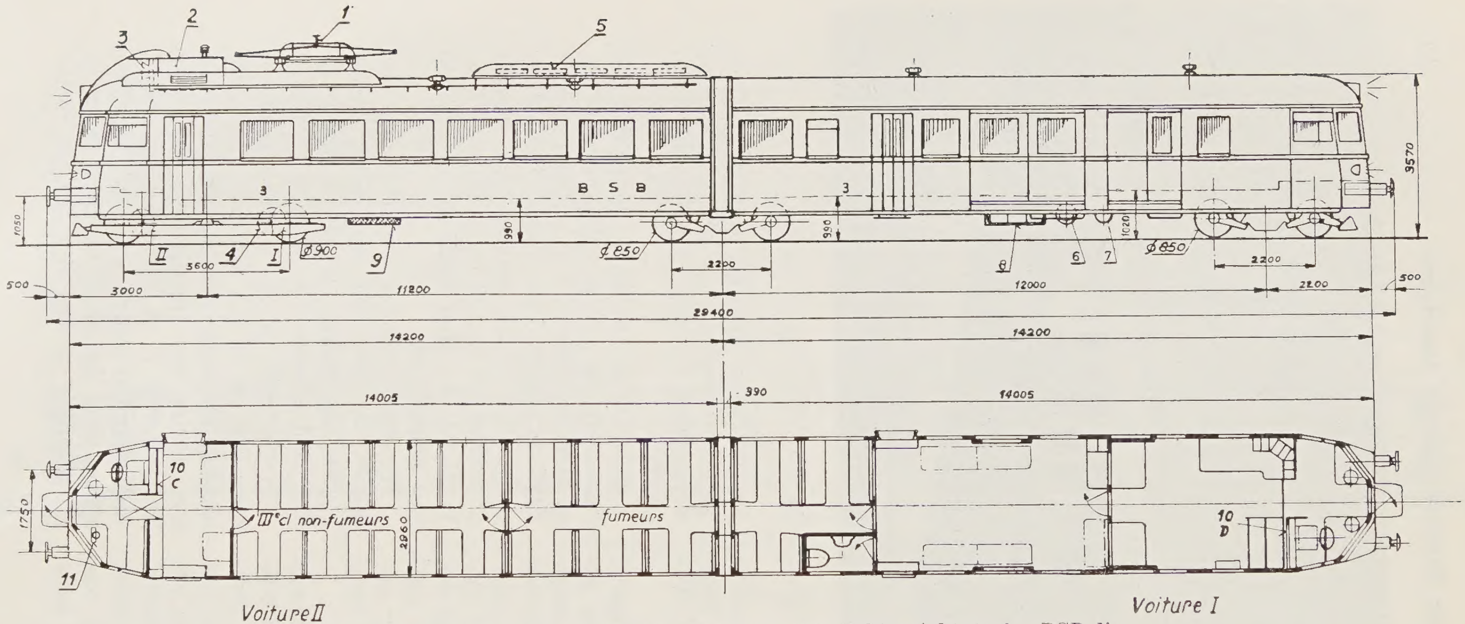


Fig. 3. — Dimensions diagram for the CFZe 2/6 681 light-weight train, BSB line.

Chief particulars:

Single-phase current	15 000 V, 16 2/3 cycles
Standard gauge	1 435 m. (*4' 8 1/2"*)
No. of light-weight trains	1

Transformer mounted in roof.
Two tramway-type motors.
Rheostatic braking.
Mechano-pneumatic contactor control
11 running steps, 9 braking steps
SIG mechanical portion.

Power at wheel tread:	
Hourly rating (at 49.5 km. = 30.7 m.p.h.)	476 H.P.
Continuous (at 54 km. = 33.6 m.p.h.)	416 H.P.
Tractive effort at wheel tread:	
Hourly rating	2 600 kgr. (*5 700 lb.*)
Continuous	2 080 kgr. (*4 600 lb.*)
Maximum	4 720 kgr. (*10 400 lb.*)
Maximum hourly speed	75 km. (*46.6 miles*)
Driving wheel diameter	900 mm. (*2' 11 1/2"*)
Gear ratio	1 in 5.23

Weight of electrical portion	10.0 t.
Weight of mechanical portion	32.5 t.
Service equipment	0.3 t.
Weight in working order	42.8 t. (*or 42.1 Engl. tons*)
Load	12.2 t.
Maximum total weight	55.0 t. (*or 54.1 Engl. tons*)
Number of seats (incl. 13 tip-up seats)	101
Standing places	39
Total passenger accommodation	140

Key to items of equipment:

1. Pantograph current collector.
2. Stepped transformer.
3. Mechano-pneumatic control contactors.
4. Traction motor.
5. Braking resistances.
6. Motor-compressor.
7. Motor-generator.
8. Battery of accumulators.
9. Traction motor shunt.
10. Distribution panels.

C. Relay panel.
D. Direct-current panel.
11. Coupling and reversing switch.

coach running on this line either a luggage van (FZ), or goods wagons.

Since the gradients on this line are as steep as 1 in 28.5 in some cases, the load hauled was limited to 15 tons. In cases of a sudden influx of passengers or goods it was often necessary to replace the light-weight coach by an electric locomotive or heavy motor coach, with a suitable train formation, which was sometimes not very easy to do.

The problem for this line, then, was to design a light train capable of carrying the maximum number of passengers at peak periods, as well as a certain weight of goods, which was restricted to 30 tons. The light train evolved after careful study was made up of two coaches, also carried on three bogies (fig. 3). The total length of the train over buffers is 29.40 m. (96 ft. 5 1/2 in.), each coach being 14.05 m. (46 ft. 1 in.) long.

Only one bogie is driving : it is of exactly the same construction as the motor bogies of the other BCFZe 4/6 trains. The two other bogies are trailers with a wheelbase of only 2.20 m. (7 ft. 2 5/8 in.). They have no axles, the four wheels being independent of each other, which favours easy running of the twin unit over the numerous curves on this line.

One of the coaches contains two third-class compartments; in the other there is a smaller compartment with lavatory, a luggage compartment which provides standing room if required, and a mail compartment with desk (fig. *4b*).

At each end of the train there is a driver's cabin with seats for passengers : the seats in the mail compartment are only available when it is not in use.

The passenger accommodation in the two trains is as follows :

I. — **BLS/BN light-weight train, Class BCF Ze 4/6. Nos. 731, 736, 737.**

Compartment.		Room available. Seats : fixed	Seats : movable	*Standing room for :*
Driver's cabin	1st coach.	2	...	...
Entrance vestibule	1st coach.	...	4	12
3rd class, non-smoking	1st coach.	50	...	...
3rd class, smoking	1st coach.	36	...	...
Entrance vestibule	1st coach.	...	3	8
3rd class, smoking	2nd coach.	20	...	...
Luggage van	2nd coach.	...	6(*)	13
Post office	2nd coach.	...	...	...
2nd class, non-smoking	2nd coach.	8	...	...
2nd class, smoking	2nd coach.	8	...	...
Entrance vestibule	2nd coach.	...	...	8
Driver's cabin	2nd coach.	2	...	...
	Total	126	13(*)	41

(*) Including one in the prisoners' cell.

There are consequently 139 seats, the total number of passenger carried, seated or standing, being 180.

The light train was found to weigh 72.5 t. (71.3 Engl. tons); the dead weight per seat is therefore 562 kgr. (1 239 lb.), and that per passenger carried (including standing) 403 kgr. (888 lb.).

employed almost exclusively. The main frames and side walls were first built separately, and then assembled in conjunction with the roof members and sheeting.

The body end walls are sloped slightly backwards in the side view; in plan, the sides are slightly inclined outwards, so as to minimise air resistance. This arrangement of the ends is dictated by the fact that the maximum speed of the BCFZe 4/6 light-weight trains has been raised to 110 km. (68.3 miles) an hour to enable them to run at the highest speeds allowable on the Swiss Federal lines.

II. — **BSB light-weight train, Class CFZe 2/6.**

Compartment.		Room available. Seats : fixed	Seats : movable	Standing room for :
Driver's cabin	1st coach.	2	...	...
Entrance vestibule	1st coach.	...	3	8
3rd class, non-smoking	1st coach.	40	...	...
3rd class, smoking	1st coach.	30	...	...
3rd class, smoking	2nd cocah.	16	...	...
Entrance platform	2nd cocah.	...	...	8
Luggage compartment	2nd cocah.	...	12	23
Post office	2nd cocah.	...	...	...
Driver's cabin	2nd cocah.	poss. 2	...	...
	Total . . .	90	15	39

There are consequently 105 seats, the total carrying capacity (seated and standing) being 144.

The dead weight of this light trains was found to be 46.6 t. (45.9 Engl. tons). The weight per seat is therefore 445 kgr. (981 lb.), that per passenger carried (including standing) being 324 kgr. (713 lb.). It is consequently 20 % lighter per seat than the first mentioned set.

Coach bodies.

The bodies of these trains are of *all-metal construction*, as those of the Ce 2/4 light-weight motor coaches already in service, and electric welding has been

The coaches have an insulating floor composed of corrugated steel sheeting, a layer of cork, and a layer of linoleum. All seats are upholstered, the second class with moquette, the third class in artificial leather, so as to afford the maximum of comfort (fig. 4*a*).

At one end of each coach, let into the

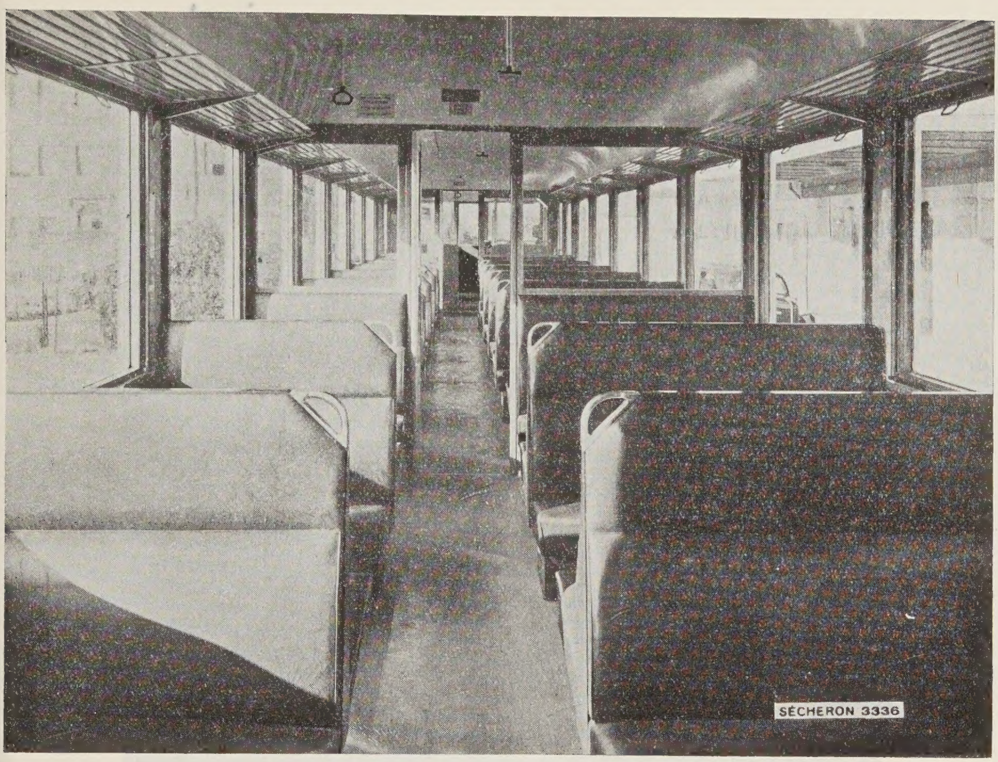


Fig. 4*a*. — Interior of 3rd-class compartment, looking towards the front from the driver's cabin.

roof, is the power transformer with the motor control contactors, a total weight of about 4 tons (see fig. 5). This arrangement has been used on light-weight motor coaches which have been in service for more than three years, and has been retained here on account of its great success. We will just mention the advantages of the arrangement : all high-tension gear outside the coach; high-tension circuits simplified to the maximum extent, viz, short connections between pantograph and high-tension fuse, and between fuse and transformer high-tension terminal; no cables connecting the secondary tapping points with the contactors; only two low-tension cables connecting the induction coil with the motor reversers; easy installation and erection of the electrical gear on account of the large amount of room available; finally, the possibility of providing a door in the end wall allowing access to the trailer vehicles, which is especially useful if the latter are passenger vehicles.

The resistances for electric braking are also mounted on the coach roofs, at the opposite ends of the latter.

The bodies for the B. S. B., Class CFZe 2/6, unit were constructed in the same way; one body has the transformer mounted in the front, and the braking resistance in the rear. This arrangement was governed by the location of the mail

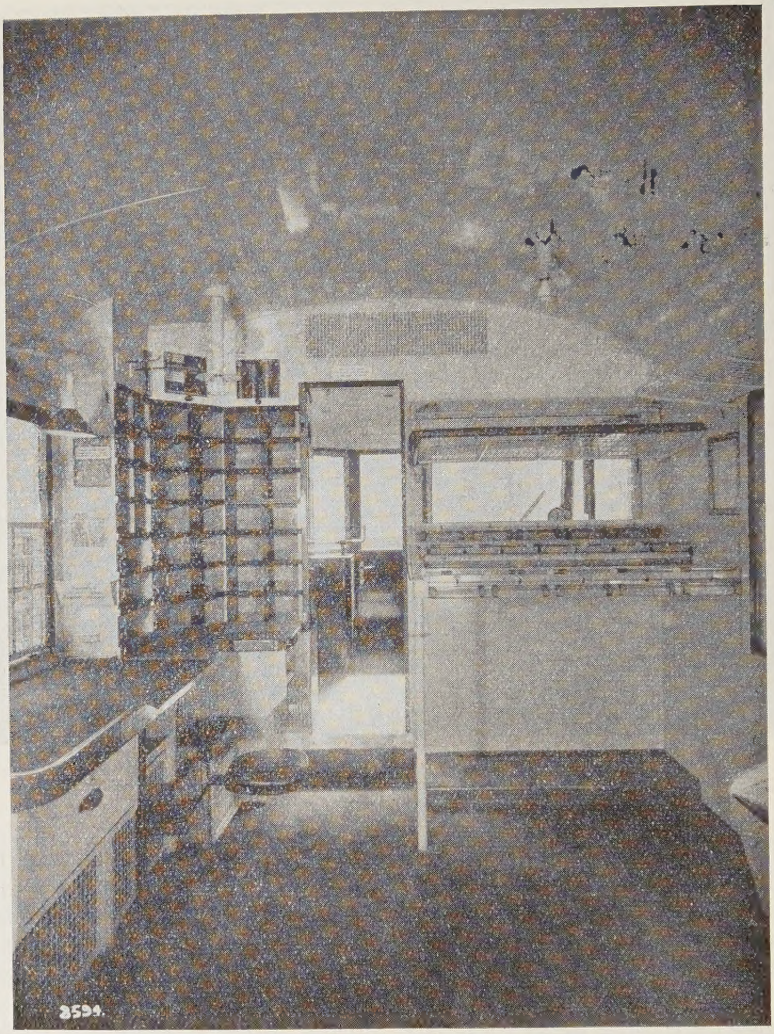


Fig. 4b. — Interior of postal compartment on CFZe 2/6 681 train.

compartment at the end of the other coach, and also enabled the wiring to the resistance to be simplified (see fig. 3).

As it is only necessary for this train to run on the Berne-Schwarzenburg line, the maximum speed has been fixed at 75 km. (43.5 miles) per hour.

At the free ends of each coach there is the standard buffing and drawgear, the Westinghouse brake hose coupling, and the electric heating jumper.

Under the underframe of each unit are hung the KLL 3 rotary compressor, made by the Swiss Locomotive Works, Winter-

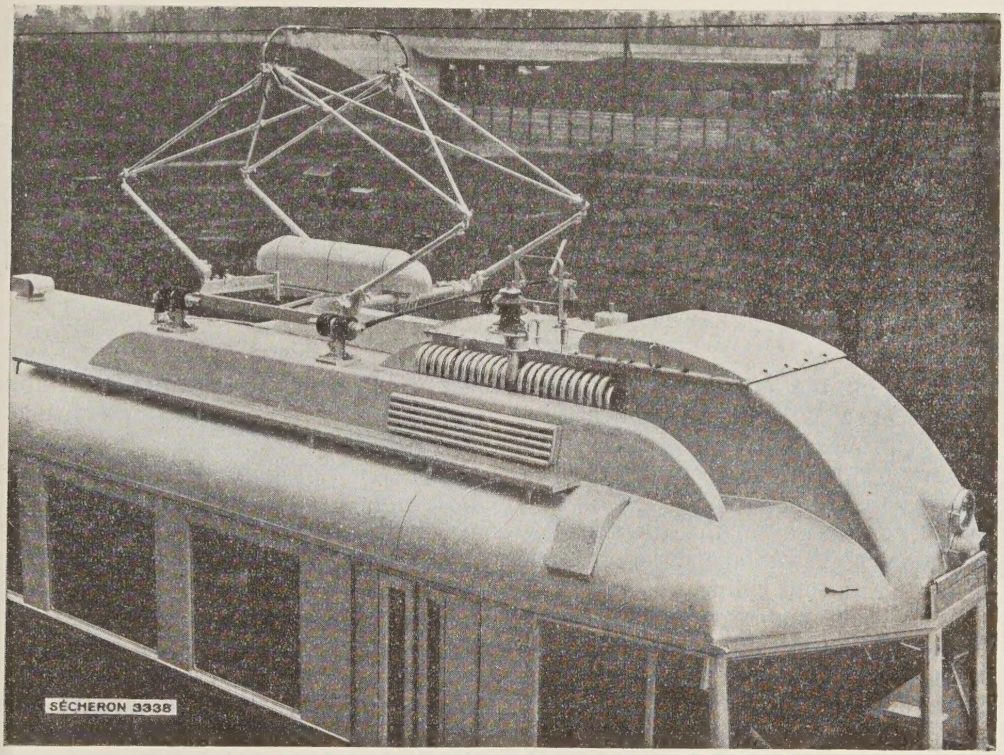


Fig. 5. — Arrangement of transformer and contactors on coach roof.

thur, with 300 litres (10.6 cu. ft.) capacity air reservoir, the A. C.-D. C. converter set for lighting and auxiliaries, the 36-volt, 100-amp./hrs SAFT cadmium-nickel battery, and the Westinghouse brake cylinders with LuR quick-acting triple valves.

The brake rigging is fitted with Stopex pattern automatic slack adjustment, made by the Charmilles Works, Geneva. The maximum brake shoe pressure is 88 % of the axle load and allows of fairly short stopping distances from high speeds.

Bogies.

The BCFZe 4/6 trains run on three bogies, of which the two outer ones are driving and the middle one a trailer only. The wheelbase of the former is 3.60 m. (11 ft. 9 3/8 in.), the latter 4.40 m. (14 ft. 5 1/4 in.). It has been possible to select such large wheelbases because the bogies are fitted with movable axles which can automatically take up *radial* positions on curves, in order to improve the running over the numerous curves on the lines over which these light-weight trains have to operate.

The bogies consist of a very stout I-section main outside frame, which at the same time shields the parts it contains (see fig. 6), and two sub-frames which house the axles and traction motors. These sub-frames rotate on a pivot

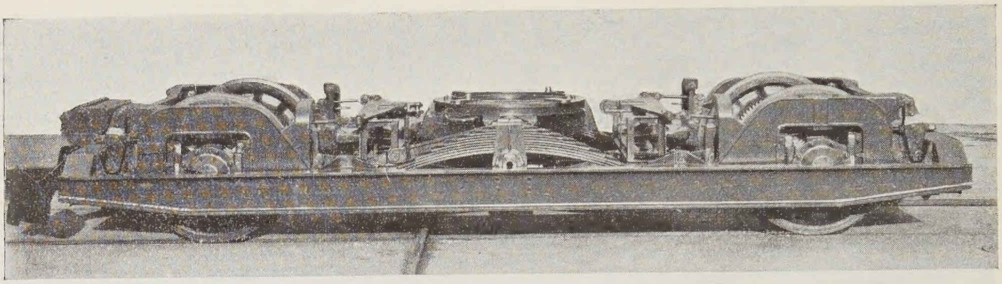


Fig. 6. — Motor bogie of light-weight train (without motors).

mounted on the main frame, and are guided by a suitably designed steering gear controlled by the coach body. According to the displacement of the bogie relatively to the body the steering gear operates in such a way that the axles take up radial positions on the curve, which makes for smooth riding.

At the front and rear of the train the bogies are fitted with guard-irons.

The bogies have been assembled almost entirely by electric welding.

The outer ends of the coaches are supported on the motor bogies by means of large centre-bearings mounted on the bolsters; the latter rest on two longitudinal laminated springs. These springs are supported at their ends either by Spencer-Moulton type rubber springs — which are for damping out the vibration of the laminated springs and making the riding easier — or by subsidiary spiral springs (fig. 6).

The motor-axle roller bearing axle-boxes support the bogie weight also by means of laminated springs (In fig. 6, these springs are hidden by the bogie frame).

At their adjacent ends the bodies are supported on the middle bogie in the same way, by centre-bearings and bolsters. As this bogie has to support two bearings with two bolsters and four longitudinal springs, it has been necessary to increase the wheelbase to 4.40 m. (14 ft.). The use of guided axles in this bogie has likewise eased the riding on curves.

We give below a brief description of these radial axles. They are of the

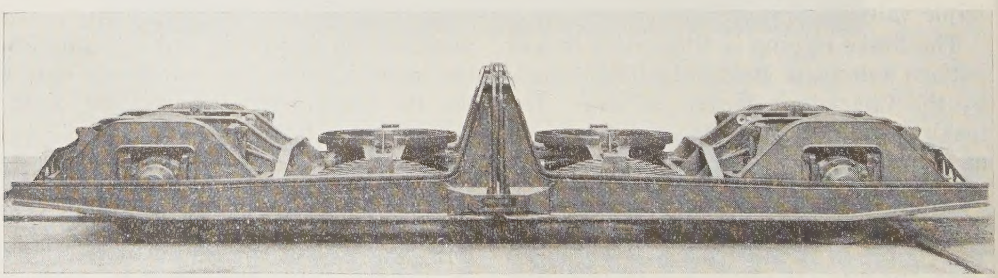


Fig. 7a. — Middle trailing bogie, complete.

Fig. 7b. — Middle trailing bogie, with two parts separated.

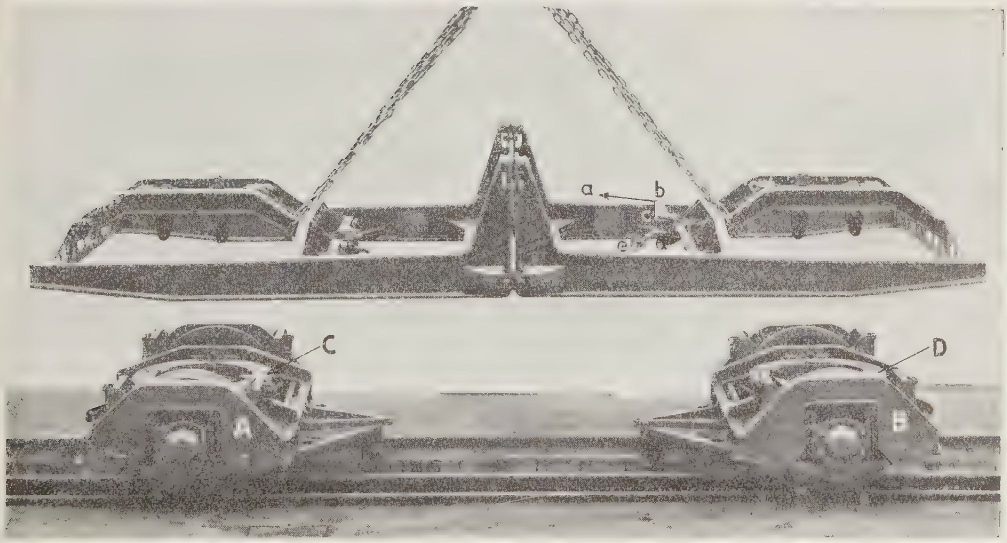


Fig. 7c. — Middle trailing bogie, showing individual components.

SJG/VRL type (for explanation, see note above), and have separate frames A and B (fig. 7*c*) arranged to swivel on pivots C and D attached to the bogie frame, which are capable of being set in radial alignment on curves by a mechanism *a-b-c-d-e* controlled by the body of the coach, to which it is attached at the point *a*.

Each angular displacement of the body on a curve, with respect to the bogie, causes a movement of the point *a* and, in consequence, a corresponding displacement of the two axles, which by this means take up a radial position on the curve.

The nett result is that even the irregular rail joints on the curve are no longer perceptible, though sometimes faulty positioning is apparent.

Each motor bogie is equipped with two traction motors. These are suspended entirely in the sub-frames, on one side by means of springs, and on the other side by supporting arms attached to the frame (fig. 8). The motors drive the axles by a quill arrangement and a « spring-and-cup » transmission of Sécheron type. The transmission of the tractive effort is smoother; at starting, no heavy shocks due to sudden increases of the driving torque are apparent.

To enable the maximum speed of 110 km. (68.3 miles) an hour to be attained with driving wheels of 900 mm. (2 ft. 11 1/2 in.) diameter without exceeding the normal motor speed at this train speed, a gear ratio of 1:3.5 was necessary. The tractive effort at the wheel-rim has not been appreciably increased by this means, the maximum motor power being concentrated on fast running.

The *CFZe 2/6 light-weight train* of the B. S. B. has a single motor bogie of ex-

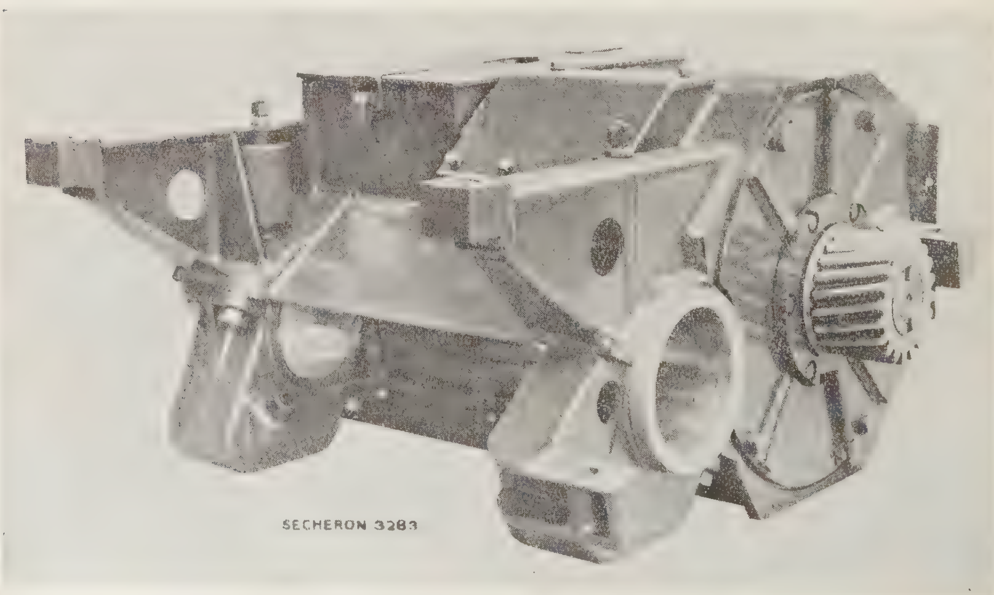


Fig. 8. — 240-H.P. single-phase motor with all-welded frame.

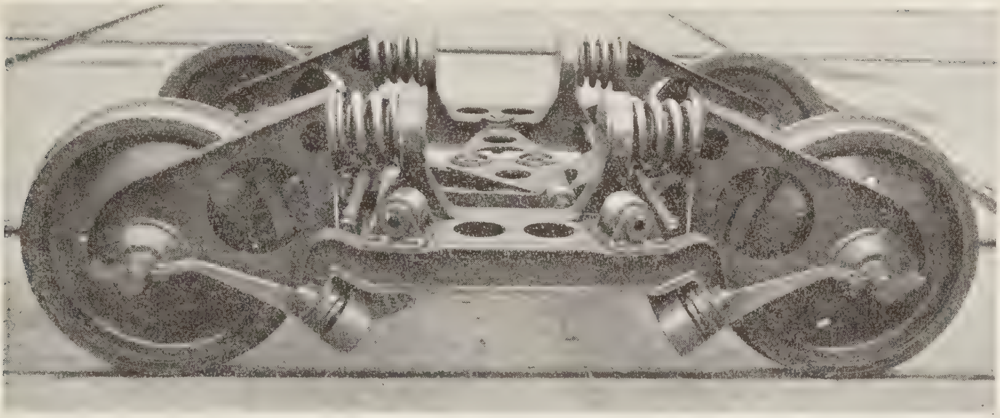


Fig. 9. — Trailing bogie of Berne-Schwarzenburg (BSB) light-weight train, with independent wheels.

actly the same type as the BLS/BN trains (fig. 6), but in this bogie the motors are nose-suspended. This was necessitated by the fact that the gear ratio is 1: 5.23, on account of the higher tractive effort required of this train.

The trailer bogies of the B. S. B. train are of quite special construction (fig. 9). In the first place there are no axles; but four separate, independent wheels per bogie. The wheels are mounted in frames forming cranked levers, one arm of which rests on stout spiral springs, while the other is attached to the main frame through further spiral springs. This method of construction ensures very smooth running free from lateral and vertical vibrations, which are so unpleasant for passengers.

The bodies are supported on the bogies by means of rectangular-section swivel bearers attached to the body, and rollers on the bogie frame. In addition, the two bodies are held together on the middle bogie by a special arrangement designed to transmit the tractive effort from the motor bogie to the draw gear of the trailing coach (fig. 9).

Electrical equipment.

The BLS/BN trains and the B. S. B. train have been fitted with the same type of electrical equipment as the Ce 2/4 motor coaches supplied by the Sécheron Works, and already in service (*). Fig. 10 shows the main current wiring diagram.

Fig. 11 shows the motor characteristic curves as determined on the test-bench.

The curves of speed and shaft output have been plotted for the two terminal voltages of 290 and 313, and on the same diagram are shown the corresponding figures for the motors of the CFZe 2/6 B. S. B. train (curves Z_1 and V_1).

The *traction motors* are single-phase commutator six-pole machines of the usual type with compensating windings and interpoles. The frame is built up of steel plates entirely by electric welding (fig. 8). In this way a very robust construction is obtained which is light and

(*) See : *Bulletin of the International Railway Congress Association*, December 1937.
Gewichtsersparnis im Transportwesen, October 1936.
Traction électrique, October 1937.

1. Pantograph current collector.
5. Circuit breaker.
6. Lead-in insulator.
7. Stepped transformer.
8. Main current transformer.
13. Contactors (mechano-pneumatic).
15 Choking coil.
17. Auxiliary braking transformer.
18*a*. Current transformer for excess current relay.
18*b*. Ammeter current transformer.
19. Coupling and reversing switch.
20. Traction motor.
21. Non-inductive shunt for running, and additional braking resistance.
22. Inductive shunt.
24. Electro-pneumatic braking contactor
25. Braking resistance.
29. Electro-pneumatic lines switch.
32. Motor coach heating contactor.
32*a*. Trailer coach heating contactor.
78. Main excess-current relay.
79. Traction motor ammeter.
80. Traction motor excess-current relay.
143. Electro-pneumatic control for coupling and reversing switch.
150. Remote control for graduation contactors.

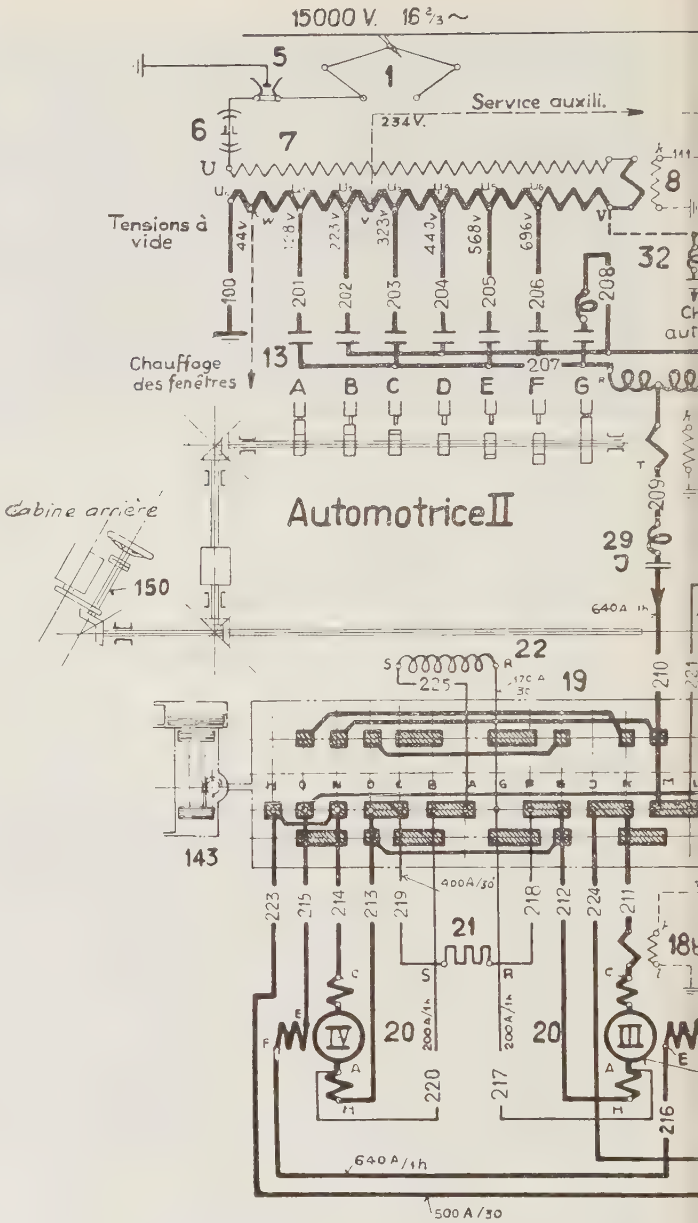
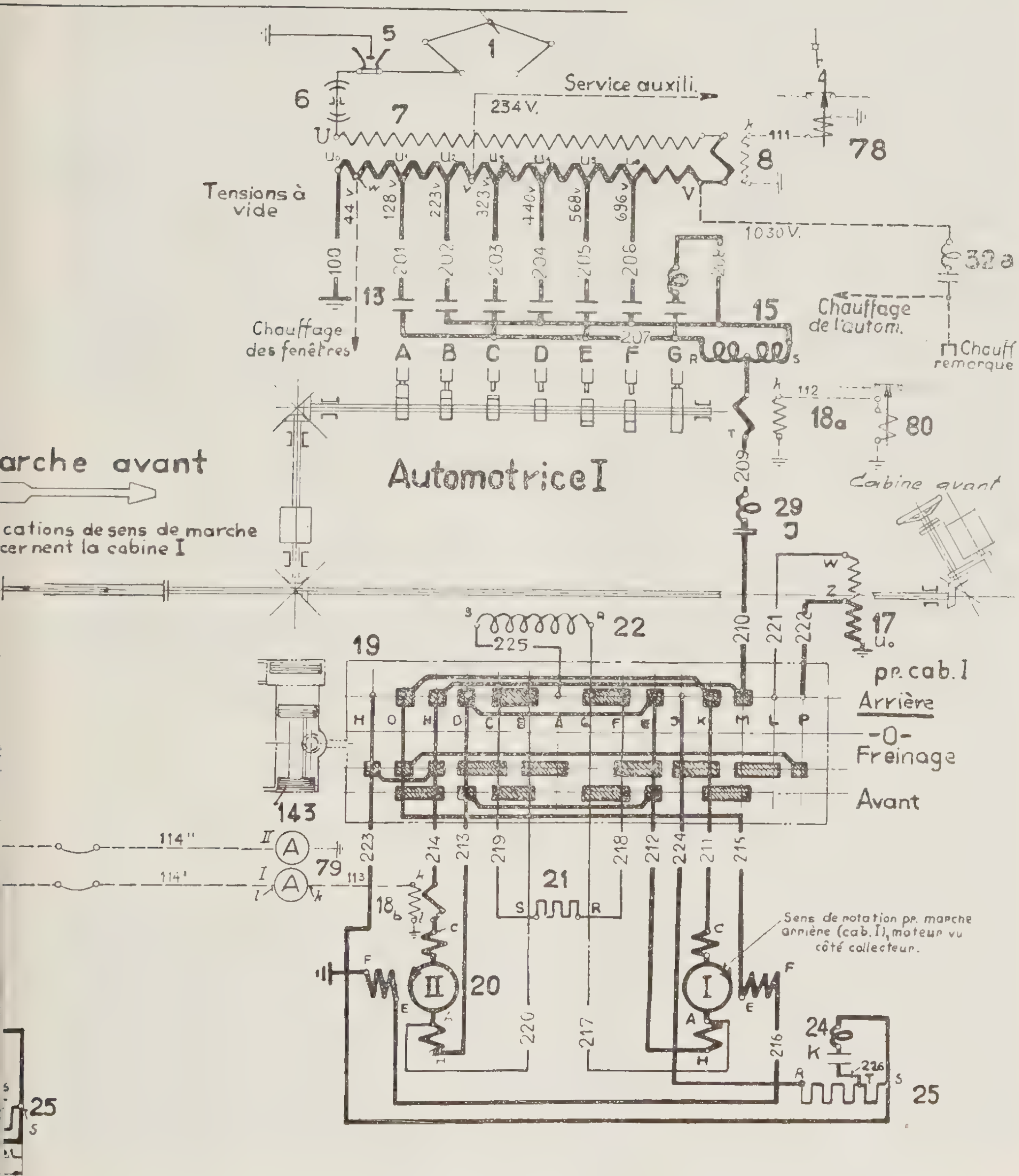


Fig. 10.

Expla

Arrière = reverse. — Automotrice I = No. 1 motor coach. — Automotrice II = No. 2 motor
motrice = motor coach heating. — Chauffage des fenêtres = window heating. — Chauffage r
The signs indicating direction of running apply to No. 1 cabin. — Sens de rotation pour marc
viewed from commutator end. — Service auxiliaire = auxiliary supply. — Tensions à vide



agram.

:
wards. — Cabine arrière = rear cabin. — Cabine avant = leading cabin. — Chauffage auto-
ing. — Freinage = braking. — Les indications de sens de marche concernent la cabine I =
eur vu côté collecteur = direction of rotation for reverse running (as from No. 1 cabin); motor

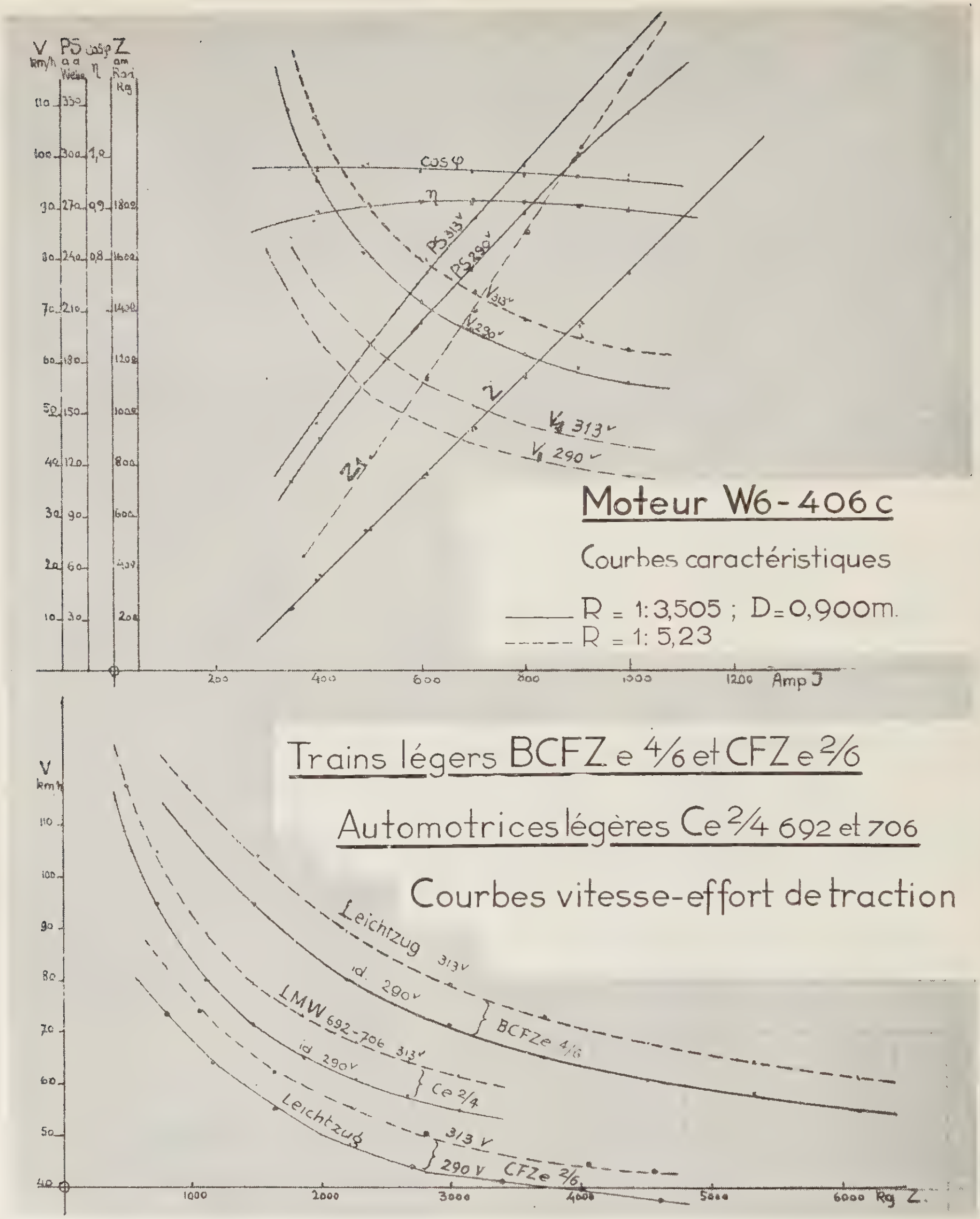


Fig. 11. — Motor characteristic curves and speed-tractive effort curves for light-weight trains.

Explanation of German terms :
P. S. a. d. Welle = shaft horsepower. — Z. am Rad = tractive effort at wheel tread. — Leichtzug = Light-weight train.

Explanation of French terms :
Moteur W6-406c = W6-406c motor. — Courbes caractéristiques = characteristic curves. — Automotrices légères... = Ce 2/4 692 and 706 light-weight motor coaches. — Trains légers... = BCF *Ze* and CF ZE 2/6 light-weight trains. — Courbes vitesse-effort de traction = speed-tractive effort curves.

in which all the components are of the exact dimensions required. The only difference between these motors and those already supplied for the first light-weight motor-coaches is that the former have a longer armature and inductor active iron, which results in a higher power.

The figures obtained on the test-bench are as follows :

I. *BCFZe 4/6 quill-drive motors with spring-and-cup transmission : gear ratio 1 : 3.5.*

(a) Hourly rating.

1. Volts, 290; amperes, 640; input, kilowatts, 180; shaft horsepower, 216; efficiency, 91 %; speed 68.5 km. (42.6 miles) an hour; tractive effort at wheel tread, 830 kgr. (1 830 lb.).

2. Volts, 313; amperes, 580; input, kilowatts, 194; shaft horsepower, 240, efficiency, 91 %; speed, 76 km. (47.2 miles) an hour; tractive effort at wheel tread, 830 kgr. (1 830 lb.).

(b) Continuous rating :

Volts, 313; amperes, 580; input, kilowatts, 177.5; shaft horsepower, 221; efficiency, 92 %; speed, 54.5 km (33.9 miles) an hour); tractive effort at wheel tread, 1 058 kgr. (2 332 lb.).

II. *CFZe 2/6 nose-suspended motors, gear ratio 1 : 5.23.*

Hourly rating :

Volts, 290; amperes, 640; input kilowatts, 180; shaft horsepower, 220; efficiency, 90 %; speed, 47 km. (29.2 miles) an hour; tractive effort at wheel tread, 1 230 kgr. (2 710 lb.).

Volts, 313; amperes, 640; input, kilowatts, 194; shaft horsepower, 235; efficiency, 91 %; speed, 61 km. (37.9 miles) an hour; tractive effort at wheel tread 1 230 kgr. (2 710 lb.).

Hence the total tractive effort at the hourly rating is 3 320 kgr. (7 320 lb.) for the BCFZe 4/6 machines and 2 460 kgr. (6 120 lb.) for the CFZe 2/6. These tractive efforts allow of the haulage of loads up to 80 tons on 1 in 45 gradients for the former units, and up to 30 tons on 1 in 28.5 gradients for the latter. The trial runs carried out with the different trains previous to their going into service have shown that these loads can be hauled easily, without undue heating of the motors especially as the gradients are not of great length and alternate with gentler gradients, or even stretches of level track.

The general layout (fig. 10) shows that the contactors are operated by mechano-pneumatic valves, which are in turn actuated by a transmission gear from the driving cabins, as on the Ce 2/4 motor coaches.

This transmission extends the length of the train, and enables the two motor groups to be controlled from one cabin. The rotation of the control wheels causes an alternate operation of the contactors, first on one group, then on the other, so that the current surges are reduced by one half. The starts are thus more gentle without loss of rapidity.

The six traction current tappings on the transformer, combined with the self-induction coil which is switched in and out alternately (see diagram, fig. 10), provide 11 starting, and 10 braking steps. On down-gradients, the electric brake is regularly employed. This operates as follows :

The motors are excited by single-phase current taken from the main transformer, the voltage of which is still further reduced by a small auto-transformer

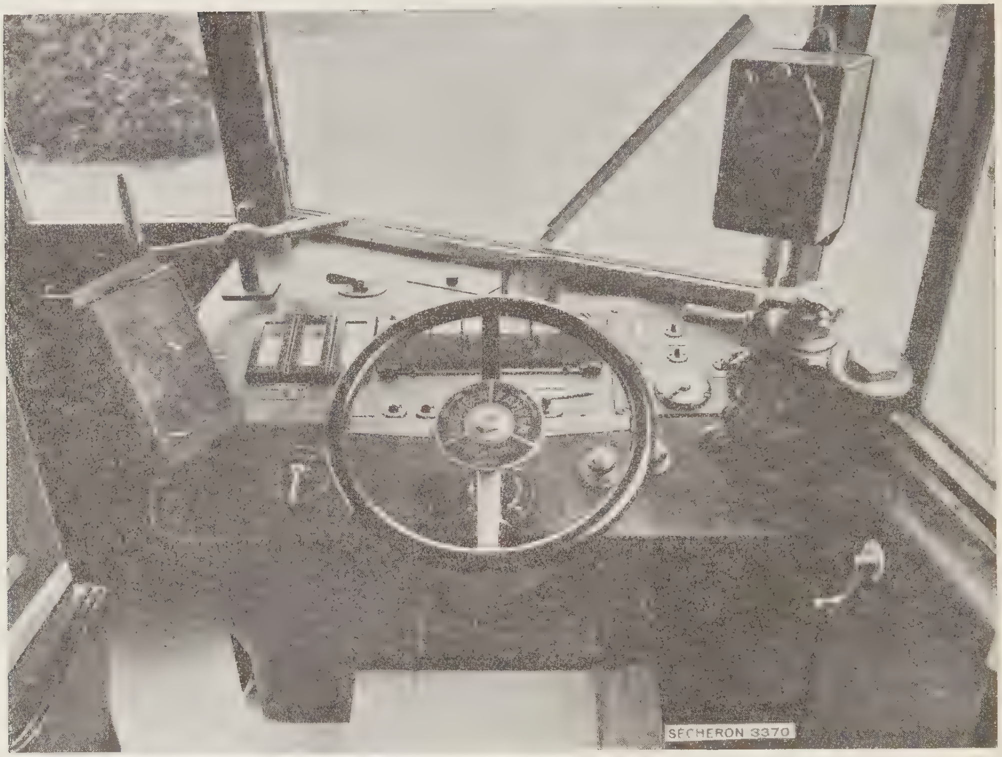


Fig. 12*a*. — Driver's desk.

Bremsen = braking. — Fahren = running.

(fig. 10, item 17) and fed to the motor fields connected in series. The induced current is absorbed in a braking resistance (fig. 10, item 25) which is of constant value except on the last notches, when an electro-pneumatic valve short-circuits a portion of the resistance, thus causing an increase in armature current and a larger braking force which enables the vehicle to be brought almost completely to a stop (in a fairly long distance, it must be confessed).

In addition, the motor circuit is broken automatically by an electro-pneumatic switch (fig. 10, item 29) when the current attains too high a value (about 900-1000 amperes), or when the automatic Westinghouse brake is applied unexpectedly (rupture of hose coupling, etc.)

The following control equipment is grouped on each driving desk (see figs. 12*a* and 12*b*). First of all come the switches, housed in a case which is locked by a special key removed by the driver when he changes cabs : reversing switch handle; pantograph operating switch; compressor switch, automatic or manual ; auxiliaries switch ; lighting switch; heating switch.

The desk also carries the switches for the track headlights, a dimming resistance for the latter, and whistle and sand-

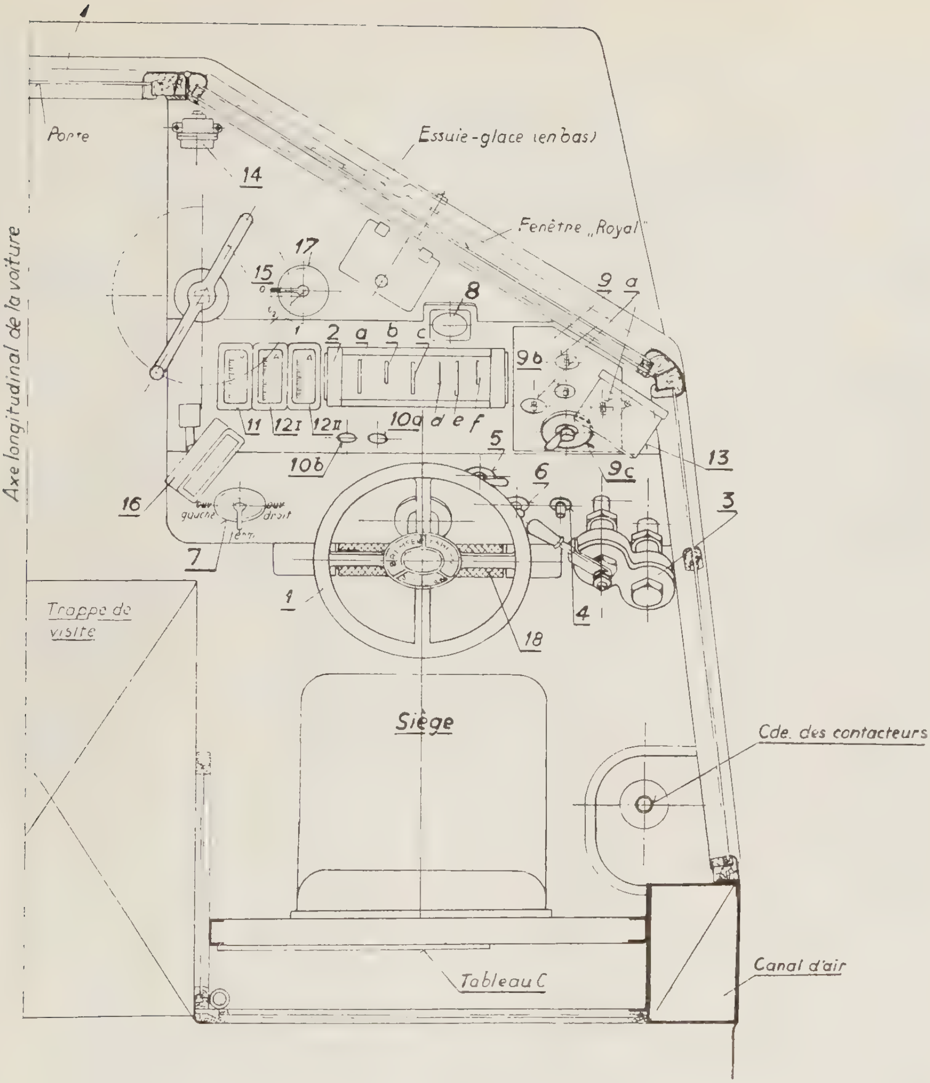


Fig. 12*b*. — Explanation of fig. 12*a*.

1. Mechano-pneumatic contactor control.
2. Switch box (B. B. C.).
   a. Reverser.
   b. Plug.
   c. Motor-compressor.
   d. Auxiliaries.
   e. Lighting.
   f. Heating.
3. Brake valve.
4. Sanding button.
5. Window-wiper control.
6. Whistle button.
7. Door control.
8. Duplex pressure gauge.
9. Lighting distribution panel.
   a. Headlight switch.
   b. Change over switch for marker day light.
   c. Headlight resistance switch.
10. Signal lamp.
    a. Signal for starting (green).
    b. For door closing (red).
11. Line voltmeter.
12I. Motor current ammeter for No. 1 motor coach.
12II. Motor current ammeter for No. 2 motor coach.
13. Speed indicator.
14. Plug point for portable lamp.
15. Handbrake.
16. Stand for holding running schedule.
17. Switch for window heating.
18. Pedal.

Explanation of French terms :

Axe longitudinal de la voiture = coach longitudinal centre line. — Canal d'air = air duct. — Cde des contacteurs = contactor control. — Essuie-glace (en bas) = window wiper (at the bottom). — Fenêtre « Royal » = « Royal » pattern window. — Ferm. = closed. — Ouv. droit = open, right. — Ouv. gauche = open, left. — Porte = door. — Siège = seat. — Tableau C = panel C. — Trappe de visite = inspection cover.

Vehicle.	Line.	Distance km. (*miles*).	Total weight of train, metr. (*Engl.*) tons.	Tkm. (*ton-miles*) worked.	Energy consumption kWh.	Specific consumption Wh/tkm. (*Wh./ton-mile*)	Remarks.
BN BCFZe4/6 736	Bern-Belp-Thun . .	34.5 (*21.4*)	153 (*150.6*)	5 315 (*3 250*)	232.4	43.7 (*71.5*)	with stops at all stations.
	Thun-Belp-Bern . .	34.5 (*21.4*)	153 (*150.6*)	5 315 (*3 250*)	208.5	39.3 (*64.3*)	
	Bern-Belp-Thun . .	34.5 (*21.4*)	153 (*150.6*)	5 315 (*3 250*)	145.9	27.5 (*45.0*)	non-stop.
	Thun-Belp-Bern . .	34.5 (*21.4*)	153 (*150.6*)	5 315 (*3 250*)	92.2	17.3 (*28.3*)	
	Bern-Thun-Bern . .	69.0 (*42.9*)	153 (*150.6*)	10 630 (*6 500*)	440.9	41.5 (*67.9*)	with stops.
BSB CFZe2/6 681	Bern-Schwarzenburg	20.9 (*13.0*)	77 (*75.8*)	1 601 (*979*)	132.1	82.5 (*134.9*)	with stops at all stations and halts.
	Schwarzenburg-Bern .	20.9 (*13.0*)	77 (*75.8*)	1 601 (*979*)	48.5	30.3 (*49.5*)	
	Bern-Schwarzenburg .	20.9 (*13.0*)	65 (*64.0*)	1 353 (*979*)	100.0(*)	74.0 (*121.0*)	non-stop.
	Schwarzenburg-Bern .	20.9 (*13.0*)	65 (*64.0*)	1 353 (*979*)	28.7	21.2 (*34.7*)	
	Bern-Schwarz.-Bern .	41.8 (*26.0*)	77 (*75.8*)	3 202 (*1 958*)	180.6	56.3 (*92.1*)	with stops.
BN BCFZe4/6 736	Spiez-Kandersteg . .	31.5 (*19.6*)	103 (*101.4*)	3 245 (*1 985*)	296.4	91.5 (*149.6*)	with stops at all stations and halts.
	Kandersteg-Brig . .	42.3 (*26.3*)	103 (*101.4*)	4 360 (*2 666*)	108.6	24.9 (*40.7*)	
	Brig-Kandersteg . .	42.3 (*26.3*)	103 (*101.4*)	4 360 (*2 666*)	394.8	90.5 (*148.0*)	
	Kandersteg-Spiez . .	31.5 (*19.6*)	103 (*101.4*)	3 245 (*1 985*)	47.7	14.7 (*24.0*)	

(*) Start on 1 in 28 1/2 gradient : 11.8 kWh, speed attained 56 km. (34.8 miles) p. h.

Line.	Distance km. *(miles)*.	Total weight of train, metric *(Engl.)* tons.	Tkm. *(ton-miles)* worked.	Energy consumption kWh.	Specific consumption Wh/tkm. *(Wh/ton-mile)*.	Remarks.
Brig-Kandersteg.	42.3 *(26.3)*	103 *(101.4)*	4 360 *(2 666)*	313.5	72.0 *(117.7)*	without stops.
Kandersteg-Frutigen . . .	18.0 *(11.2)*	103 *(101.4)*	1 855 *(1 134)*	21.4	11.5 *(18.8)*	
Frutigen-Kandersteg . . .	18.0 *(11.2)*	103 *(101.4)*	1 855 *(1 134)*	176.0	95.0 *(155.3)*	
Kandersteg-Brig.	42.3 *(26.3)*	103 *(101.4)*	4 360 *(2 666)*	88.3	20.2 *(33.0)*	
Spiez-Brig-Spiez.	147.6 *(91.7)*	103 *(101.4)*	15 210 *(9 300)*	847.5	55.8 *(91.2)*	with stops at all stations and halts.
Bümpliz-Neuchâtel. . . .	38.7 *(24.0)*	142 *(139.8)*	5 550 *(3 390)*	250.4	45.1 *(73.7)*	with stops at all stations and halts.
Neuchâtel-Bümpliz. . . .	38.7 *(24.0)*	142 *(139.8)*	5 550 *(3 390)*	264.9	47.7 *(78.0)*	
Bümpliz-Neuchâtel. . . .	38.7 *(24.0)*	138 *(135.8)*	5 350 *(3 270)*	159.6	29.8 *(48.7)*	without stops.
Neuchâtel-Bümpliz. . . .	38.7 *(24.0)*	138 *(135.8)*	5 350 *(3 270)*	186.3	34.8 *(56.9)*	
	High-speed trial run.					*Max. speed.* Km. *(Miles)*
Bern-Neuchâtel	42.9 *(26.7)*	75 *(73.8)*	3 210 *(1 960)*	117.1	36.5 *(59.7)*	90 *(56)*
Neuchâtel-Yverdon	36.2 *(22.5)*	75 *(73.8)*	2 715 *(1 660)*	64.4	23.7 *(38.8)*	90 *(56)*
Yverdon-Lausanne	39.1 *(24.3)*	75 *(73.8)*	2 930 *(1 790)*	103.0	35.2 *(57.6)*	110 *(68.3)*
Lausanne-Montreux . . .	24.6 *(15.3)*	75 *(73.8)*	1 845 *(1 130)*	44.0	23.9 *(39.1)*	90 *(56)*
Montreux-Sion	67.9 *(42.2)*	75 *(73.8)*	5 090 *(3 110)*	107.8	38.9 *(63.6)*	120 *(75)*
Sion-Brig	53.1 *(33.0)*	75 *(73.8)*	3 980 *(2 430)*	165.0	41.5 *(67.9)*	110 *(68.3)*
Brig-Kandersteg.	42.3 *(26.3)*	75 *(73.8)*	3 170 *(2 270)*	220.5	69.5 *(113.6)*	100 *(62)*
Kandersteg-Thun	41.9 *(26.0)*	75 *(73.8)*	3 140 *(1 920)*	40.5	12.9 *(21.1)*	80 *(50)*
Thun-Bern	31.3 *(19.4)*	75 *(73.8)*	2 350 *(1 440)*	87.2	37.2 *(60.8)*	110 *(68.3)*
Total . . .	...	...	28 430 *(17 400)*	1 039.5	36.5 *(59.7)*	...

ing buttons. On the left are the handles controlling the valves for the electro-pneumatic door-operating gear; the meters : — line voltmeter, and ammeter for each motor group; window-wiper control, and switch for heating the « Securit » glass front window. Finally there are the Westinghouse driver's brake valve and the « dead man's » pedal, on which the driver must always keep his foot while the train is running.

The speed-control wheel is automatically locked by the key of the case mentioned above.

Test runs.

Immediately after their final handing-over at the Sécheron Works, the light-weight trains were subjected to a series of test runs on all the BLS/BN system lines in order to ascertain their hauling capacity, and also the running times at maximum speeds allowed according to the condition of the track gradients and curves. These trials terminated with a high-speed test run over flat country and on mountain lines for a total distance of 380 km. (236 miles) of which 74 km. (46 miles) were over the steep gradients of the B. L. S.

The results of these runs were considered satisfactory, and the trains could then be put into regular service immediately afterwards.

During the trial runs we measured the energy consumption of these trains by a meter connected to the transformer. The energy consumption is therefore measured at the contact line. If the consumption at the substation is required, these figures must be increased by about 10-15 %, according to the condition and construction of the contact line. We give these figures in table form.

By way of comparison we give below a few consumption figures for trains

Line.	Weight of train. Metr. (*Engl.*) tons.	Motor unit : 70-t. loc. 65-t. railcar.	Tkm. (*ton-miles*) worked.	Energy consumption. kWh.	Specific consumption Wh./tkm. (*Wh./ton-mile*)	Remarks.
Bern-Belp-Thun. . .	122 (*120.1*)	Loc Ce4/6	4 220 (*2 580*)	200	47.5 (*77.7*)	
Thun-Belp-Bern . . .	198 (*194.8*)	Do.	6 882 (*4 209*)	272.7	39.6 (*64.8*)	
Bern-Schwarzenburg .	89 (*87.6*)	Railcar CFe2/6	1 655 (*1 019*)	136	62.3 (*101.9*)	including electric heating.
Schwarzenburg-Bern .	70 (*68.9*)	Do.	1 310 (*801*)	49.5	37.6 (*61.5*)	
Bern-Neuchâtel . . .	225 (*221.4*)	Railcar Ce4/4	9 640 (*5 895*)	197.7	20.2 (*33.0*)	
Neuchâtel-Bern . . .	166 (*163.4*)	Do.	7 097 (*4 340*)	166.7	23.5 (*38.4*)	
Bern-Neuchâtel . . .	244 (*240.1*)	Loc. Be4/6	10 470 (*6 403*)	393	37.6 (*61.5*)	do.
Neuchâtel-Bern . . .	162 (*159.4*)	Do.	6 930 (*4 238*)	340.7	49.1 (*80.3*)	do.

hauled by heavy motor vehicles (70-ton locomotives, 65-ton motor coaches).

In comparison with those for the light-weight trains, these records show that, for the same weight, the latter have a consumption almost equal to, if not lower than, that of trains hauled by locomotives or heavy motor coaches. Since the weight of the latter forms very nearly half or one third of the train weight, it follows that the light-weight train will achieve a considerable energy saving.

However, this saving will never amount to one third, since it is impossible to run nothing but light-weight trains on the different lines, as, on account of their heavy loading, certain trains (e. g. for season-ticket holders, tourists, clubs, etc.) have to be hauled by locomotives or heavy motor coaches.

The light-weight trains were put into service on the various BLS/BN lines as soon as they had completed their trials. Since then their running has been satisfactory and without incident. Slight alterations have been made to the trailer bogie suspension in order to lessen lateral oscillation. With this exception, it may be said that these trains have given as much satisfaction to the travelling public, who are delighted to ride in coaches of the most up-to-date type running at the highest speeds allowable, as to the Railway Administration, which is achieving considerable savings in traction current.

Their operation during the next few years will show how to provide for their maintenance in the most rational manner, while keeping them to the heaviest possible duty, adapted, however, to the volume of traffic.

[621. 431. 72 (.85) & 621. 434 (.85)]

Experimental railcar for the Central Railway of Peru,

By Dipl.-Ing. J.-L. KOFFMANN,

Ware (Herts), England.

In order to improve their passenger service, the Central Railway of Peru, known as the highest railway in the world (1), some time ago decided to introduce railcars on a larger scale, and several experimental units, both diesel and petrol-engined, have been ordered and put into operation (2). The problems confronting the operation of railcars on the railway concerned are indicated by the profile of the line (fig. 1) which, between Callao, Peru's largest Pacific port, and the Galera tunnel, is continuously uphill for 172 km. (107 miles), incorporating many gradients up to 1 in 25. Another difficulty encountered is that, due to the increasing rarefaction of the atmosphere the power output of the engines is reduced by approximately 1 % per 100 m. (330 ft.) (fig. 2), or to about 57 % at the highest point of the line. Furthermore, although the air temperatures at the high altitudes are frequently very low, they vary over a large range, whilst the capacity for carrying away heat from the radiators is reduced due to decreased air density, which also results in a lower boiling point of the cooling water. In view of these difficulties it was obvious that railcars could only be

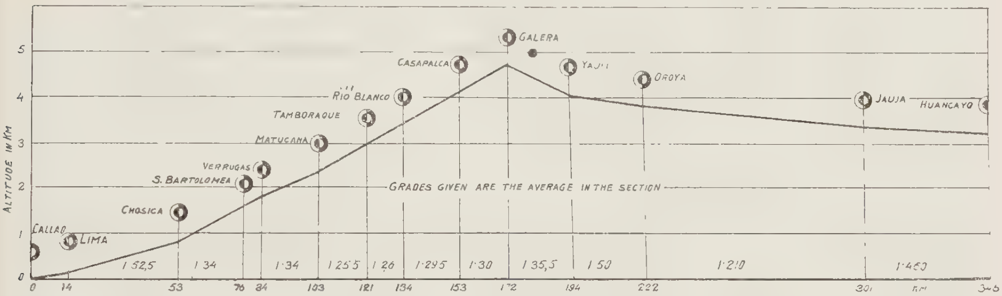


Fig. 1.

(1) JUKES : « The Central Railway of Peru ». *The Locomotive*, 1935, pages 163, 180.

(2) « British built South American Railcar ». *Railway Gazette*, Diesel Supplement, June 1936, p. 1143.

KOFFMANN : « Steam Railcar Converted to Diesel ». *Railway Gazette*, Diesel Supplement, September 1938, p. 431.

« Local Railcars for Peru ». *Railway Gazette*, Diesel Supplement, November 1938, p. 939.

« Lightweight Railcars, Central Railway of Peru ». *The Locomotive*, 1937, p. 271.

KOFFMANN : « Railcar Operation at High Altitudes ». *The Locomotive*, 1938, p. 392; 1939, p. 21.

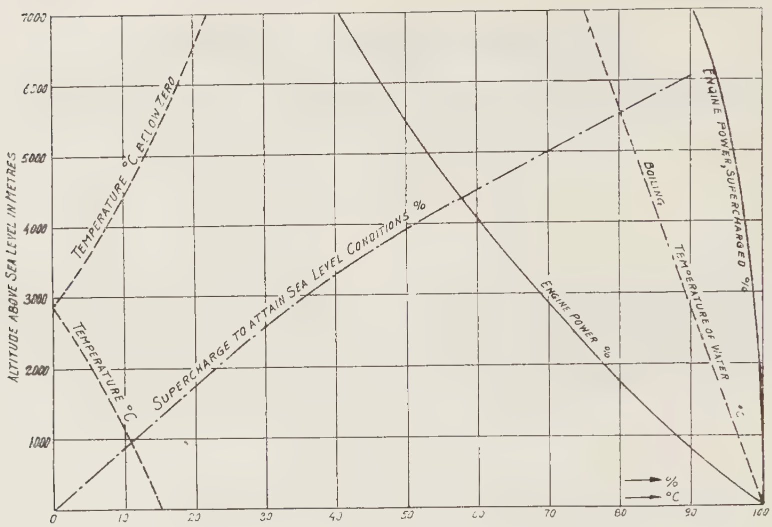

ALTITUDE ABOVE SEA LEVEL IN METRES
TEMPERATURE °C BELOW ZERO
TEMPERATURE °C
SUPERCHARGE TO ATTAIN SEA LEVEL CONDITIONS %
ENGINE POWER %
BOILING TEMPERATURE OF WATER °C
ENGINE POWER, SUPERCHARGED %
7000
6000
5000
4000
3000
2000
1000
0
10
20
30
40
50
60
70
80
90
100
%
°C

Fig. 2.


FERROCARRIL

Fig. 3.

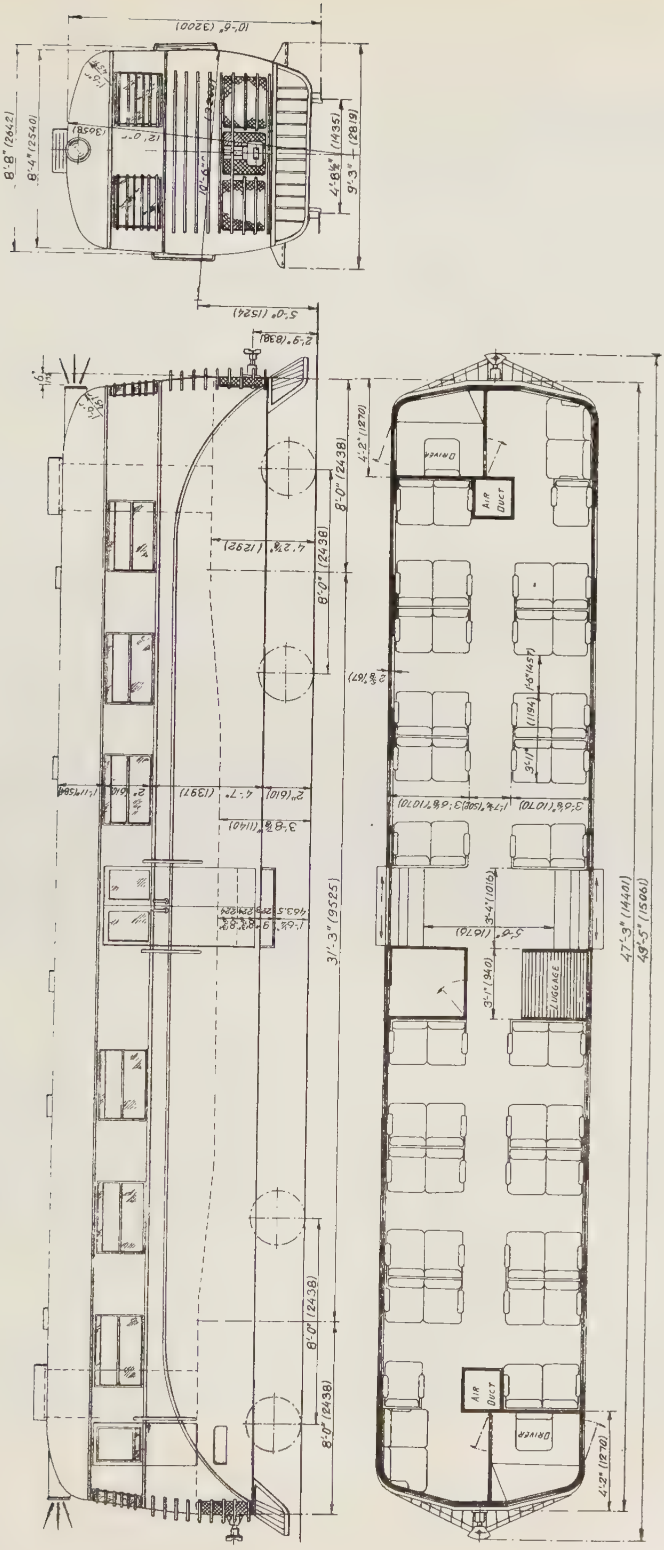

10'-6" (3200)
8'-8" (2642)
8'-4" (2540)
12'-0" (3658)
4'-8½" (1435)
9'-3" (2819)
5'-0" (1524)
2'-9" (838)
8'-0" (2438)
4'-2" (1270)
AIR DUCT
DRIVER
LUGGAGE
31'-3" (9525)
47'-3" (14401)
49'-5" (15061)

Fig. 4.

successful when ensuring maximum efficiency, i. e. low dead weight per passenger carried, this in turn requiring a maximum of floor space unobstructed by engines and auxiliaries.

To fulfil these requirements an experimental car (figs. 3 and 4) has been recently built by D. Wickham & Co. Ltd., of Ware, to the specifications and inspection of Messrs. Livesey & Henderson, Consulting Engineers to the Peruvian Corporation. With this unit high-speed petrol engines were adopted due to their low height, but in order to ensure a reasonable power output at high altitudes supercharging has been considered advisable.

The provision of exhaust driven turbo-blowers, as widely used with diesel engines, was not possible due to the high exhaust gas temperatures of petrol engines, which are of about 850° C. as compared with 500° C. with diesel engines, and mechanically driven blowers were adopted instead.

Due to numerous sharp curves, along the line, the bogie wheelbase has been limited to 8 ft. (2.44 m.) while the wheels are 26 in. (660 mm.) in diameter.

The bogie frame (fig. 5) is of welded 1/4 in. plates with 5/16 in. flanges top and bottom, and the superchargers, engine and transmission are mounted on two 5-in. channels. In order to keep the engine under floor level the front bogie axle has been cranked and provided with free wheels, each wheel rotating on two substantial self-aligning SKF roller bearings placed as far apart as possible. The adoption of free wheels, already successfully tried with previous railcars of the Central Railway, besides permitting to design a short, yet low power bogie also improves the riding qualities by eliminating the lateral oscillations of the axle as well as reducing curve resistance [3]. The reduction of curve resistance with a bogie provided with free wheels throughout amounts to :

Fig. 5. — Bogie for Central of Peru railcar.

$$N = \frac{100\, s^2}{a^2 + s^2}\ \%$$

[3] « The free wheel on railway vehicles ». *The Locomotive*, 1938, p. 331.

where s is the distance between the tread circles of the opposite sided wheels of the bogie, i. e.,

$$s = \sqrt{a^2 + (2b)^2},$$

where a is the bogie wheelbase and $2b$ the distance between centres of tread circles. As the bogie described has free wheels at the front axle only, the reduction in curve resistance amounts to 13.75 %.

In order to reduce the weight of the bogies, as well as to improve the riding qualities, standard hornblocks, which were also subject to rapid wear on the dusty sections of the railway, were replaced by radius bars positively securing the axleboxes to the frame. The axleboxes are provided with underhung semi-elliptic springs with a deflection of 0.96 in./ton (24.5 mm./t.), which carry the bogie frame through rubbing pads, the spring ends being guided by 4 in. wide clips.

Railway vehicles, when travelling at high speed, tend to develop lateral oscillations which increase with tyre wear, and finally assume the characteristic form known as bogie hunting. These oscillations result in secondary oscillations of the car body which at high speeds comes within the resonance range, thus leading to highly unpleasant high-frequency vibrations. The wave-length of the lateral oscillations can be increased to some extent by a suitable shape of rails and wheel treads [4], and by reducing the amount of play between the bogie and axleboxes.

The possibility of improving the riding qualities of cars by reducing the axlebox play to a minimum i.e., by positively attaching them to the frame has been dealt with at considerable length, both theoretically and experimentally, at various times by numerous investigators [5], but as pointed out by HEUMANN, with sometimes great inaccuracy and generalisation. Whilst all investigators assume that the rolling resistance is not dependent on the velocity of slipping, Carter and Davies, as well as Rocard assume, in accordance with the theory of « creep » and « pseudo-glissement », respectively, a dependence of the rolling resistance on the velocity of slipping.

The equation of the path of a single axle is well known : it represents a sine-curve of fortuitous amplitude and of a wave-length

$$L = 2\pi \sqrt{\frac{r \times b}{T}},$$

where r denotes the wheel radius, $2b$ the distance between centres of tread circles, and T the tangent of the coning angle.

The wave-length of a four-wheeled bogie the axles of which have no play in the frame is increased by an « elongation » factor E, the movement of the central

(4) HEUMANN : « Lauf der Drehgestell-Radsätze in der Geraden ». *Organ für die Fortschritte des Eisenbahnwesens*, 1937, p. 149.

(5) CARTER : « The electric locomotive ». *Proceedings of the Inst. of Civil Engineers*. Vol. CC1 ; London, 1916.

« Railway electric traction », pages 47 and 57. London, 1922.

ROCARD : « La stabilité de route des locomotives ». Paris, 1935.

HEUMANN : « Lauf von Eisenbahnfahrzeugen mit zwei ohne Spiel gelagerten Radsätzen in der Geraden ». *Glasers Annalen*, 1938. Vol 62, pages 25 and 43.

DAVIES : « Some experiments on the lateral oscillation of railway vehicles ». *Journal of the Inst. of Civil Engineers*, March 1939, p. 224.

point of the bogie following a sine-curve with a wave-length of

$$L' = 2\pi \sqrt{\frac{r \times b}{T}} \times E$$

wherein in accordance with DAVIES

$$E = \sqrt{1 + \frac{(a/2)^2}{b^2}}$$

and, in accordance with HEUMANN

$$E = \sqrt{\left[1 + \frac{a^2}{4(b^2 - s^2)}\right] \times \frac{1}{1 - \frac{T}{r \times b}(b^2 - s^2)}}$$

wherein a is the bogie wheelbase, whilst

$$s = 0.71\,(a + b) \times r \times f$$

where f is the coefficient of friction.

With the car described, $r = 13$ in. (0.33 m.), $a = 8$ ft. (2.44 m.), $T = \frac{1}{20}$ and $2b = 59\ 1/16$ in. (1.50 m.). The wave-length of a single free axle therefore will be L = 45.9 ft. (14 m.) whilst in accordance with DAVIES L' = 86.6 ft. (26.40 m.) as against L' = 106.5 ft. (32.50 m.) in accordance with HEUMANN, f being assumed to be 0.2. The radius of curvature of the path of the bogie centre is, in accordance with Heumann,

$$R = \frac{1}{y \times A},$$

wherein

$$A = \frac{T}{r \times b} \times \frac{b^2 - s^2}{b^2 - s^2 + \frac{a^2}{4}}\left[1 - \frac{T}{r \times b}(b^2 - s^2)\right],$$

which in our case amounts to A=0.00264 while y is the side displacement of the bogie centre. With $y = 1/4$ in. (6.35 mm.) we obtain R = 2525 ft. (770 m.) for the free axle and R = 19 585 ft. (5 970 m.) for the bogie centre. Although the above results are not exactly valid with the bogies described, due to the use of free wheels on one axle, and also to the fact that a certain lateral displacement is permitted by the spring guides, they indicate the advantages offered in restricting the movement of the axles against the bogie frame.

The car body is carried on the bogies by means of helical springs. A helical spring with a deflection of 1 in. per ton (25.4 mm./t.) is carried in a tubular guide at each side of the bogie. The spring supports a plate with a universal joint carrying a rod which extends through the top plate of the bogie and carries a universal joint at the lower end which supports the car body on an anchor-shaped bracket. This suspension incorporates the advantages of a swing bolster, and is of simple and light, yet robust design. The springs allow a wide range of deflection, this being of importance not only for the riding qualities of the car, but also due to the fact that on many overseas railways there exists sudden superelevation up to 5 in. (127 mm.) which, when passed at low speeds, may with hard springs result in the lifting and consequent derailment of the inner wheels of the car. A Houdaille hydraulic shock absorber is fitted between each

side of the bogie and the body. The centre pin guide in each bogie is restricted in its side movement by a helical spring with a deflection of 0.5 ton per inch (200 kgr. per cm.) so as to damp out side swinging, a displacement of 1 in. to each side being allowed.

The engine is a twelve-cylinder Lincoln unit, developing 139 B.H.P. at 3 000 r.p.m. The cylinders are arranged at an angle of 67°, in banks of six, the cylinder bore and stroke being 3 1/8 in. and 4 1/2 in. respectively. The total piston displacement is 414 cu. in., the maximum engine speed is 4 250 r.p.m., and the cylinder firing order is 1-4-9-8-5-2-11-10-3-6-7-12. The compression ratio is 6.38 to 1, whilst the standard compression pressure is 138 lb. per sq. in. (9.66 atm.) at 1 000 r.p.m. This engine has been adopted for its simplicity, low weight and height, and simple maintenance. It also has the advantage that spare parts can easily be obtained from local dealers.

Each engine is provided with two centric type 640.G. superchargers (fig. 6), each having a theoretical output of 195 cu. in. (3 200 cm³) of free air per revolution, and driven from the front end of the engine crankshaft by a total of four 7/8-in. V-section belts. The superchargers are of the positive displacement type with four flat radial vanes, made of nickel-chrome air-hardened steel and separately hinged on a central spindle by means of ball bearings, the vane carriers being of 38-tons/sq. in. manganese bronze. As vanes are individually counterweighted, there is little load on the ball bearings. A clearance of about 0.006 in. is maintained between the vanes and the Electron housing. The vanes are driven against the pressure head through the displacement drum which is of Hiduminium RR. 56, and is mounted eccentric to the housing and spindle. The drum, which is mounted on its own ball bearings, drives the vanes through trunnion blocks and is in turn driven from the central spindle through a pair of internal and external gears. This arrangement has the advantage of affording a « through drive » but it reduces the effective speed to 0.66 of the speed of the driving shaft. The trunnion blocks, which are slotted, cylindrical rods of Fabroil, drive the vanes and permit of a limited amount of rocking or wobble and seal the working space from the central compartment. Automatic lubrication is ensured by an oil pump driven through a reduction gear on the rear end of the

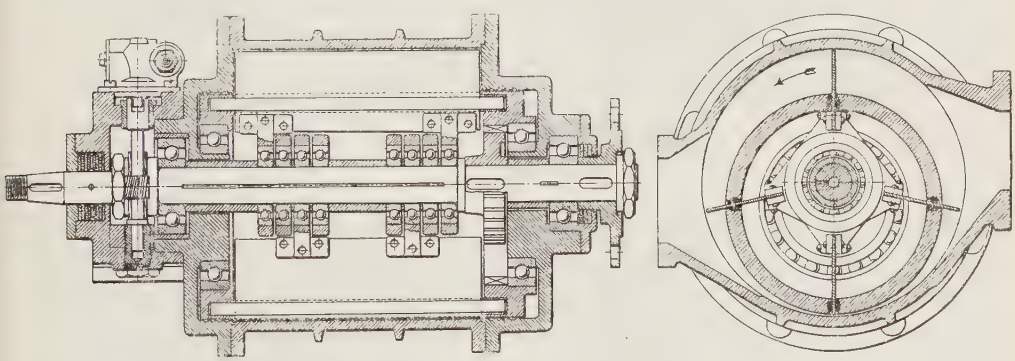


Fig. 6.

central shaft. The complete supercharger weighs about 60 lb., its output and power consumption being shown by fig. 7. Owing to the fluctuation of the rates of displacement of the engine pistons and the blower vanes, the blowers are connected not directly to the inlet parts of the engine, but through suitably dimensioned pipes which act as air-storage chambers, both pipes being cross-connected to equalise differences in pressure.

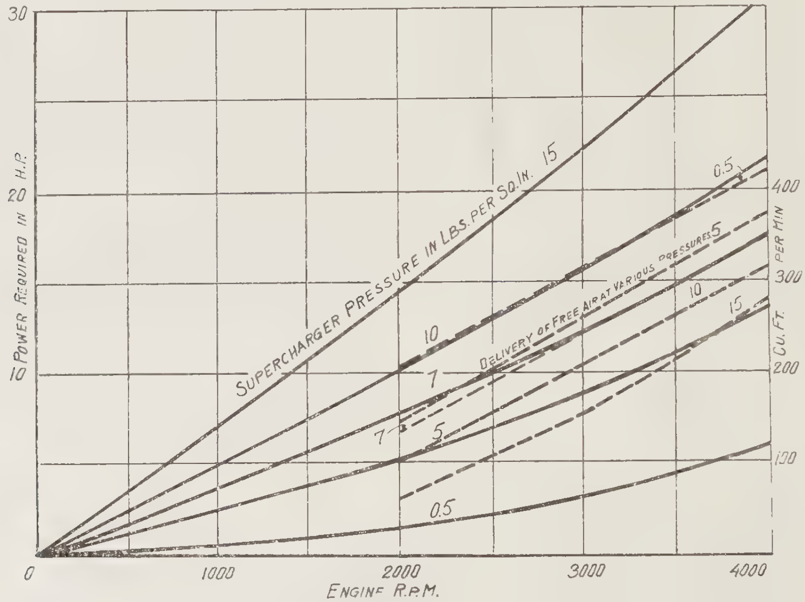


Fig. 7.

The blower represents the first stage of compression, the second being effected by the compression stroke of the engine. As the gas expansion is effected in the engine cylinders only, a supercharged en-engine works, compared with the total compression, with a reduced expansion ratio, which for a certain maximum compression pressure — which in a carburettor engine is determined by the detonating characteristics of the fuel — will of necessity be lower if supercharging is used, and reduced expansion means reduced thermal efficiency and reduced fuel economy, the fuel consumption being furthermore increased due to losses effected by the supercharger drive. The resulting increase in fuel consumption is up to 50 % with a blower pressure of about 7 lb. per sq. in. The increase in fuel consumption is compensated for to a certain degree by the improved distribution of charge between the different cylinders when supercharging, due to the fact that compression of the charge in the blower generates heat, and the heat helps to vaporise the fuel. If the fuel is completely vaporised before it reaches the branch-offs in the manifold, distribution is practically perfect. However, in an engine with a system of manifolding that gives substantially equal distribution without supercharging, there is,

of course, no possibility of material improvement in this respect.

In order to obtain a rise in output it is not only necessary to increase the pressure of the charge of the combustion air, but it is a matter of essential importance to thoroughly scavenge the engine cylinders with fresh and comparatively cool air. This scavenging is therefore regarded to-day as an integral feature when employing superchargers.

Formerly, the only idea of how to raise the output of a given engine was by increasing the pressure of the charging air, but this is accompanied by an increase of the temperature of the charge. The output of an internal combustion engine with a given swept cylinder volume depends, however, on the complete burning of a definite quantity of fuel in relation to the weight of the air contained in the cylinder, the theoretical amount of air weight required being $W_{LB} = 4.25\ (\frac{8}{3}C + 8\ H + S)$. With petrol mixtures about 12 to 13 lb. of air is theoretically required for 1 lb. of fuel, but in reality nothing like this quantity of fuel can be burnt completely since it is impossible to get so fine a distribution of fuel in the air that every molecule of air is intimately mixed with its correct share of fuel, i. e., in the proportion of 13 to 1. In practice it is possible at normal load to obtain smokeless combustion with a proportion of air to fuel of 25 to 1.

If the temperature of the charge of air is increased by pre-combustion, the weight of the air introduced will not be increased in the ratio of the absolute su-

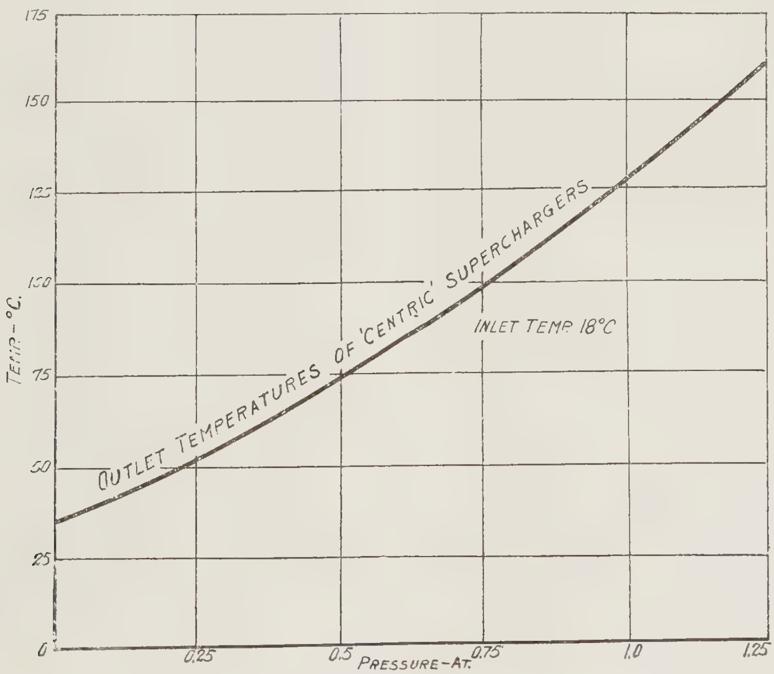


Fig. 8.

percharging pressure to the absolute admission pressure of the ordinary engine, but will have to be multiplied by the reciprocal of the ratio of the absolute temperature of the introduced charge to the temperature of the atmosphere. In fig. 8 the end temperatures are plotted as a function of the pressure ratio. From this it can be clearly seen how greatly the temperature rises, particularly, with increasing compression. As the supercharging pressure ratio is increased, the ratio of the specific weight of air lowers. Consequently, by merely increasing the supercharging pressure the rate of increase of output of the engine diminishes. The power required for the supercharger drive also rises with increasing pressure, while the efficiency falls, so that there is no gain in going beyond a certain supercharging pressure. Up to now, supercharging air pressure has been kept below 6 lb. per square in., as designers have refrained from exceeding the hitherto usual maximum cylinder pressure, being content with supercharging pressures of this order, and with the introduction of scavenging, so far as diesel engines are concerned. The actual process of scavenging is simple and presents fewer problems than that of supercharging. No special devices are required, but only a special setting of the valve gear to pass the charging air to exhaust during the scavenging period.

In four-stroke engines all the gases can be blown from the combustion space by a quantity of air of about 8 % in excess of the swept cylinder volume. After the filling of the compression space is completed, the surplus air passes through it, thus cooling the inner walls of the cylinder, the inlet and exhaust valves and the cylinder head passages.

The weight of air used in combustion depends on its temperature and pressure. The temperature of the enclosed charge depends on the waste gases which remain in the cylinder walls, piston, liner, cylinder cover, valves, etc. But scavenging reduces the quantity of gases remaining in the cylinder, and when it is adequate, completely displaces them, and also lowers the temperature of the cylinder walls. For both reasons, therefore, the temperature of the charge admitted is lower and its weight higher, making possible a considerable increase in output.

Unfortunately it is not possible to employ scavenging with standard petrol engines with carburettors, and it is to be hoped that engines with direct injection will be developed for operation at high altitudes where supercharging is desired, and scavenging required to assure an all-round success.

Slight difficulties were experienced in starting and at low engine speeds, due to a vacuum of up to 7 lb. per sq. in. (0.5 kgr. per cm^2) in the intake pipe, but this can be reduced by careful adjustment of the carburettors. Another difficulty may be experienced in lubricating the blower, due to the influence of the petrol mixture passing through it from the carburettor. Nothwithstanding the disadvantages mentioned, it has been found advisable to employ charging blowers to ensure a reasonable power output at high altitudes, as here the problem of getting maximum power from a given bulk and weight is of greater importance than overall efficiency, this in turn ensuring smaller overall dimensions and weights with the car concerned.

The drive from the engine is effected through a multiplate dry clutch mounted on the flywheel, and a Mylius type « d » four-speed, air-operated, preselective synchro-mesh gearbox, and hence through a cardan shaft to the reversible Wickham

axle drive, the gear ratio of which is 5 to 1.

Braking is by clasp brakes applied by 4-in. (100 mm.) pressed steel brake cylinders, one for each wheel. Compressed air for the brakes, gear control and auxiliaries is supplied by two Barr-Hall compressors, delivering 9 cu. ft. of air at 975 r.p.m. The hand brake at the driver's left applies the brakes on the driving wheels of both bogies. Air-operated sanders are provided at each side of the driving wheels, and a 32-gallon (145 litres) petrol tank is carried at the rear end of each bogie.

As mentioned before, special attention had to be paid to ensure efficient cooling in employing two ample sized radiators at the front of each bogie. Each radiator is provided with a fan fixed on the shaft of the supercharger blower. As the wind along the line concerned blows mostly from the sea at a speed almost equal to the speed of the vehicle, the car runs uphill in dead air, and although sufficient cooling can be ensured with the front engine, the rear unit is usually too hot. In order to eliminate this, both cooling systems are interconnected (fig. 9), thus leading the water from the front radiator to the rear engine and vice versa, so that while the rear engine gets the cooler water, the front engine obtains the warmer, this permitting to obtain practically equal temperature in both engines.

A duct to the roof is provided over each bogie to permit the hot air coming from the radiator and passing over the engine, to escape through the roof.

The body framework consists mainly of square tubular sections, no separate underframe being employed to support the car body. As is well known, the square tubular section forms an ideal member for meeting all stresses involved, these features permitting a body design leading to a considerably reduced weight. The whole body is designed as a tube with the result that horizontal forces, such as wind pressure, shocks and centrifugal force on curves acting upon the body are transferred to the longitudinal members, thus eliminating any deformation of the body. A further advantage is due to the fact that in order to achieve the strength desired it is not always necessary to arrange side pillars and floor cross members in one plane, the same results being obtained with cross members arranged lengthwise against the pillars.

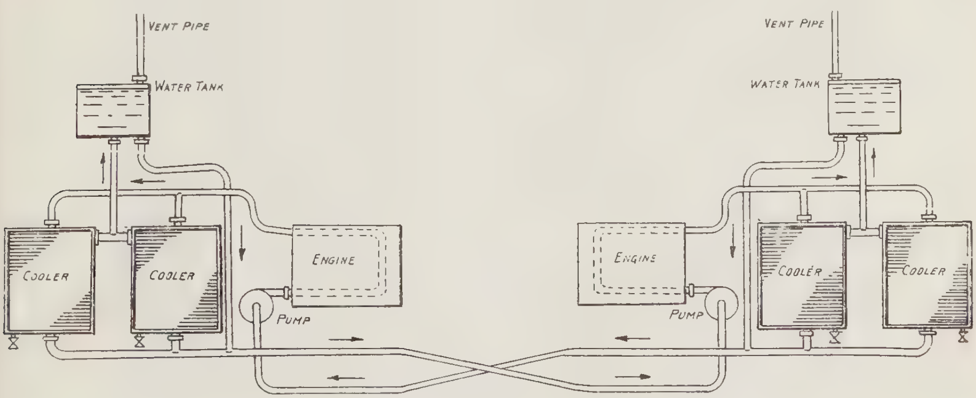


Fig. 9.

Here the horizontal forces acting upon the pillars result in a bending moment transmitted to both roof and floor longitudinal members, and as these are torsion-proof tubular units they transmit the forces to the adjoining roof and floor cross members, thus permitting better utilisation of all members in meeting the forces involved. As the use of tubular sections ensures better utilisation of the matter for cross stiffening the body, in many instances cross members can be eliminated altogether, being replaced by pillars, which stresses the longitudinal members in torsion. The whole structure is welded, the ends of the tubular members being sealed by welding, to prevent any air passage, small holes being of no importance as they are soon rust closed, while the whole design is more rust-proof than with angular sections, which are rust affected from both sides.

With the car described the longitudinal and cross members are 2 3/8 in. wide, 1/8 in. thick, square tubes, which although they are 25 % heavier than round tubes of the same diameter are 60 % stronger in resisting the bending moments involved. The use of square tubes also considerably simplifies construction due to easy and more dependable welding. The floor is carried by four square tubular members extending over the whole car length and stiffened by tubular cross members. Additional strength is ensured by horizontal members connected to the floor frame by side pillars. These stiffening members run at about 1 ft. 8 in. (500 mm.) under floor level at both car sides, and are suitably connected by cross members. Another square tube belt line is provided round the car at the window level, and also over the windows, while the side pillars are also square tubes. The central vestibule is designed as a tubular box frame stiffened by steel side sheeting and the entrance step framework. The side and roof sheeting is of aluminium, screwed to brackets welded to the pillars.

Entrance to the central vestibule is by a double sliding Alpax door, a lavatory and a small luggage compartment adjoining the entrance.

Water to the lavatory as well as to the drink-water filter is supplied from a tank carried underneath the floor by means of compressed air. The seats in the passenger compartment (fig. 10) have tubular steel frames, well upholstered with brown leather, while an adjustable seat is provided at the driver's compartment.

The handles at the driver's stand (fig. 11) from left to right are : reversing valve handle, throttle control, gear selector handle, and clutch valve handle. Both the engine throttles and the clutch valve are mechanically operated by means of Teleflex cables as recently developed for aircraft and ship engine room telegraph control. The switch and instrument board which, besides the usual gauges, also contains supercharger pressure gauges, is at the driver's left. The sander valve is foot operated.

The main reason for employing hand control is that in the operation of a railcar no steering is required, so that while the car is running the driver has nothing whatever to do with his hands, if throttle and braking are put on pedals. It is hardly advisable, from a psychological point of view, to leave a man at an important work that calls for a high degree of concentration on the smoothness and safety of operation, with his hands idle. One's thinking is too much tied up with what the hands are doing. Hands will not stay idle, and if the driver, when operating a car, begins to do with his hands other things that take away his attention from safety and smoothness of

Fig. 10. — Driver's stand.

Fig. 11. — View of passenger compartment.

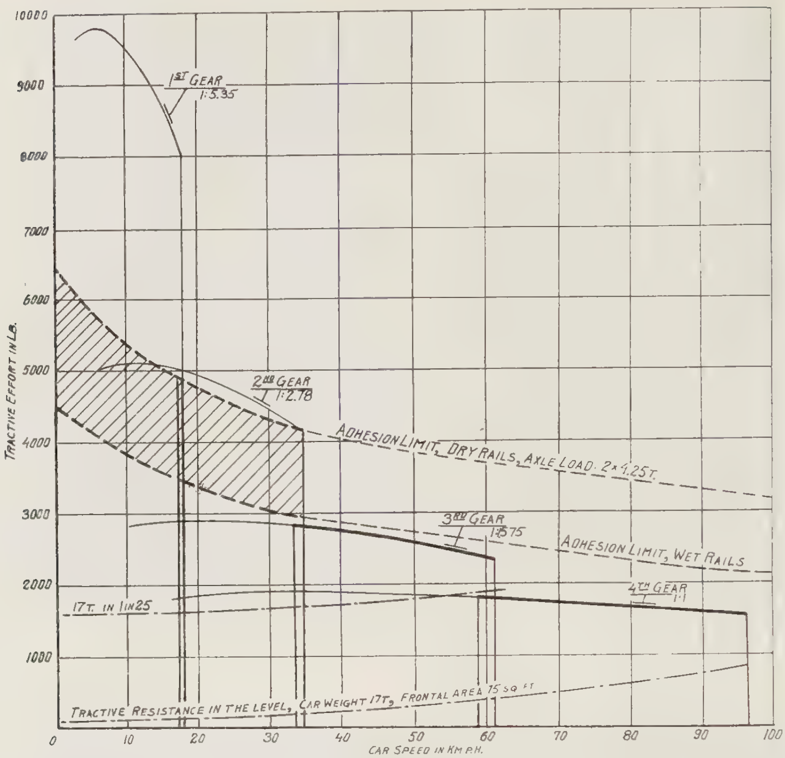


Fig. 12.

the vehicle, poor driving will be the result. Hand operation with proper kinds of movement can be much more accurate than foot operation, and due to the flexibility of hands, wrists, arms and body, the driver may make levers move accurately in a vertical or horizontal direction, even though the body is not in a fixed position in a seat.

The front end of the car is protected against damages in case of collision with animals traversing the line, by a number of horizontal tubes, while the windows are also protected against damage by vultures sitting on the rails and rising immediately in front of the car. The car is painted in three shades of grey.

The car weight is 12.4 tons empty and about 17 tons with luggage and full complement of passengers. The performance curves (fig. 12) have been plotted with the assumption of a loss of 42 H.P. in the first three gears and 36 H.P. in the fourth gear due to transmission efficiency and auxiliary drives. Whilst the available tractive effort cannot be wholly utilised for acceleration due to limits imposed by adhesion, a speed of about 60 km. (37 miles) p.h. can be maintained over 1 in 25 gradients.

The speed-time and speed-distance curves (fig. 13) show the good accelerating qualities of the car. About 3 seconds are required for changing from one gear to

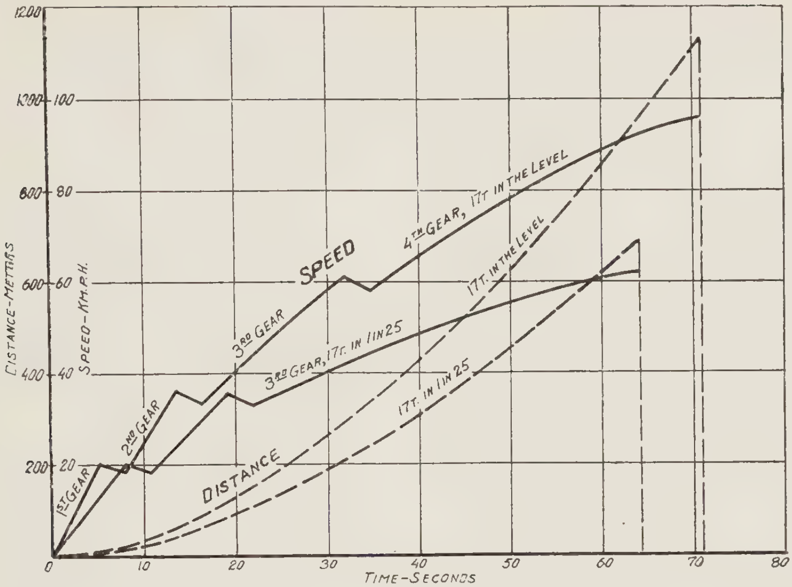


Fig. 13.

another, and as the drop in speed due to this could not be effectively determined with the car speedometer, this has been calculated in accordance with well known methods (6). The light weight of the car, combined with the unobstructed floor space and high power/weight ratio, results in a vehicle well able to meet railway requirements, besides being an inexpensive and effective tool for meeting road competition at reduced operating expenses.

(6) OPATOWSKI : « La perte de vitesse des automotrices à transmission mécanique au cours du changement de rapport de transmission ». *Les chemins de fer et les tramways*, Aug.-Sept., 1936.

[621.43 & 669]

The use of hydronalium for railcar construction,

by OTTO TASCHINGER,

Reichsbahnoberrat, Reichsbahn-Zentralamt, Munich.

(From Zeitung des Vereins Mitteleuropäischer Eisenbahnverwaltungen.)

Railway vehicles, which have to make frequent starts or climb up gradients in regular service, in other words, which are generally called upon to exert an accelerating or climbing effort, must be as light in construction as possible, because it is under these conditions that the fuel economy made possible by the reduction in the dead-weight or the possibility of shortening the running times is particularly large. This consideration especially applies to trailers, with or without control gear, of internal combustion engined railcars, on account of the low power of the machinery with which railcars are equipped.

The following methods may be resorted to in order to build railway vehicles of as light a construction as possible :

(1) Raising the maximum limits of the permissible stresses applicable to the constructional materials hitherto employed, or using constructional materials of higher strength;

(2) Adaptation of the dimensions of all the constructional parts to the stresses exerted on them, to enable the tensions to be uniformly spread in each case over the whole of the construction.

(3) Elimination of members which do not support the structure from the static point of view, so that the load may be carried as far as possible by all the parts used in the construction of the vehicle;

(4) Choice of a material having the maximum specific resistance (resistance divided by the specific weight) and the most favourable specific modulus of elasticity.

Under present service conditions, which are made more difficult by the high speeds demanded, and by the introduction of internal-combustion engines, the dynamic stresses in railway vehicles are capable of reaching a multiple of the static load; but as these stresses have not yet been determined with sufficient accuracy for them to be taken into account in the calculation of the resistance, it does not appear advisable to raise the admissible stress limits of the constructional materials hitherto employed. On the contrary, experience has shown the necessity, in the case of certain constructional elements, of appreciably reducing the stress limits which up to now have been looked upon as correct.

Within the last few years, much use has been made abroad of constructional steels of particularly high tensile strength for railway vehicles. For example, at the 1937 Paris international Exhibition, there was on view an alternating-current twin motor coach unit, the body and frame of which were of stainless steel. In America, also, many vehicles built of stainless steel have been put into service in recent times. In Germany, there is no question at the moment of employing constructional steels of very high tensile strength, because of their high content of elements which should be avoided. Moreover it is not necessary to use them in view of the fact that for the purpose of light construction, methods Nos. 2 to 4 given above enable the same result to be attained.

In 1926 the German Reichsbahn ordered two half train sets for the Berlin Underground lines, in which use was made

of light metals for the coach bodies, by way of experiment. In spite of the fundamental drawbacks of composite construction, the programme ruled out the use of light metals for those constructional parts which are of primary importance in guaranteeing the safety of the vehicles (the sole bars, longitudinals, and main gusset plates), on account of their low impact resistance, and also on account of the fact that they do not easily absorb deformation work.

In one half train set, use was made for experimental purposes, for one of the motor coaches, of *Skleron* (aluminium with copper, zinc, and a little silicon). For the other motor coach and the two trailer coaches. *Lautal* (4 % copper, 2 % silicon and 94 % aluminium) was used. The heavily stressed parts of the frame were made of « St. 37 » (23.5 Engl. tons per sq. in.) steel, whilst for the other parts of the frame, namely : cross-bearers, fittings and floor beams, use was made of light metals, as in the case of the body. Similarly, the whole of the interior arrangements, namely : wall panelling, full-height and semi open partitions, sliding door runways, sliding doors and seat legs, were specified to be of light metals. The interior lining consists of lautal plates, 2 mm. (0.078 in.) thick, the grab handles and luggage rack frames of drawn lautal tubing, the luggage rack brackets, and the majority of the fittings of cast silumin, whilst the door handles and lamp rosettes, are of cast lautal. Silumin, which is specially corrosion resisting, was employed for the window frames.

The construction of the second half train set was very similar to that of the standard type of Metropolitan coaches of the period. The lautal bodies had the same dimensions as those of the steel coaches. The interior panelling was of wood, but the partition and door panels were of light metal. The fittings and other small parts were the same as in the first half train set; the window frames were, however, of lautal.

The light-metal parts were assembled one to the other and to the steel parts with rivets made of lautal. A coat of paint was carefully applied between the steel and the light metal to guard against corrosion.

In proportion to the weight of 65 t. (64 Engl. tons) of the light-steel half train set (38 t. = 37.4 Engl. tons for the motor coach and 27 t. = 26.6 Engl. tons for the trailer) the weight saving was 2.4 + 2.2 = 4.6 t. (4.53 Engl. tons) with the first half train set, and 3.7 + 3.9 = 7.6 t. (7.48 Engl. tons) with the second half train set.

The load tests carried out on these coaches registered deflections some 20 % to 50 % greater than those of the corresponding steel coaches. However, the bodies of the light-metal coaches fairly resumed their initial positions after the load had been removed, as did the side wall plates with the more accentuated bellying of the side walls than on the steel coaches. There were no measurable deformations of the roof sticks, transoms and solebars. After an experimental service of about six years, corrosion took place in the light metal at the points where it was jointed with the steel. The other constructional parts gave complete satisfaction.

Besides the German Reichsbahn, the Halberstadt-Blankenburg (Harz) Ry. Company carried out a trial in 1926-27 with a light-metal coach. This was a 4-wheeled diesel railcar built in the workshops of the Waggonfabrik Ürdingen, the body of which, for the first time, was constructed entirely of light metal, the side walls being arranged to take part of the load. The constructional material used for the body, namely *Lautal* necessitated special profiles which to-day can be regarded as superseded, in view of the improved knowledge of constructional materials of this kind and the progress made in the methods of

machining them. The greatest thickness of plate was 10 mm. (13/32"); this limit could not be exceeded, for the homogeneous texture of lautal could not at that time be guaranteed. The plates were rivetted together cold. The panelling also was formed of lautal plates, which were also rivetted cold.

During a period in service of eight years, this coach gave rise to no difficulties of any description. No corrosion occurred in either the body supports nor in the wall panels; it is true that the coach was stabled in a dry shed, in a uniform temperature, and that no other vehicles entered the shed, in which it was therefore not exposed to the effects of the exhausts of any other engines.

For some time, an ever increasing use has been made of light metals in the construction of the body work of motor cars and motor-buses. At the International Automobile Exhibition held in Berlin in 1937, there were on show for example a large number of motor-buses and motor cars in which light metals had been used for the whole of the body work, and consequently also for the load carrying parts. [See *Automobiltechnische Zeitschrift*, 1937, No. 17 : « Strassenfahrzeuge aus Leichtmetall — Eine zeitgemässe Betrachtung » (Road vehicles built of light metals — a study of present day practice »), by Dipl. Ing. Brauer.]

In view of the favourable results obtained by the Halberstadt-Blankenburg Ry. Company, and the use of light metals in the construction of aeroplanes and motor cars, as well as for railway vehicles abroad, and in particular in view of the fact that in the case of railcars with internal-combustion engines the low tare weight of the vehicle is of capital importance, the German Reichsbahn in 1934 ordered two internal-combustion-engined rail motor coaches for a maximum speed of 75 km. (46.6 miles) an hour, the bodies of which, except for negligible details, were constructed of light metal. In order to obtain an exact comparison and show up the advantages of these light-metal coaches, an order was placed at the same time for some light steel coaches, with the same layout and fitted with similar driving equipment; but instead of adopting for the light-metal vehicles the method of construction used for the steel vehicles, which were also of a light type, it was understood that a new method of construction, in which due account would be taken of the specific properties of the light metal, would be used.

The design and construction of the light-metal coaches and of the steel vehicles were placed in the hands of the same builder, namely : the Maschinenfabrik-Augsburg-Nürnberg (M.A.N.), of Nuremberg, with the object of ensuring construction according to the same basic principles (see fig. 1).

Fig. 1. — Exterior view of railcar.

The constructional material chosen for the light-metal coaches was *hydronalium* made by the « J. G. Farbenindustrie » Bitterfeld, and the manufacturer's light-metal workshop with its extensive experience of the machining of light metals collaborated with Messrs M.A.N. The calculations for the bodies of the vehicles were made by Professor Wagner, of the Charlottenburg Technical High School, who drew up special formulæ for calculating construction with thin plates. Supervision of the designs and the bulding was done by the Munich Central Office of the Reichsbahn; and as an entirely new constructional mate-

rial was to be employed, the engineers responsible for the designs were given ample liberty of action. It was obvious from the very beginning that the first light-metal coaches would cost appreciably more than the light-steel coaches, for as regards the machining of the steel the most economical methods were already known, after long years of experience, with the result that the light-steel coaches could be built under the most advantageous conditions from the point of view of price. On the other hand, in order to achieve the object in mind, it was necessary in the case of the light-metal coaches to find a satisfactory technical method of construction without regard to the first cost at the beginning. It is only after a sufficient amount of experimental results about this absolutely new construction, obtained in the workshops and in service, has been collected, that it will be advisable to go into the question anew, in the light of the experience gained in the workshops, in order to bring down the initial expenditure to the minimum. When the cost price is taken into account, for reasons of an economic nature, it may be better to make the maximum weight saving indicated by the ideal technical solution agree with the optimum weight saving. It will be possible, in particular, to re-consider the profiles of the constructional parts, as manufacture by mass production results in totally different possibilities for light metal. For example, the use of the shaping press with light metals enables the most complicated profiles to be produced and to replace profiles assembled by rivetting or welding by a single pressing, thereby reducing the labour costs for manufacture. Practically all possible cross sections can be made in this way, and adapted to the strength conditions. Fig. 2 shows a few particularly interesting sections employed in the hydronalium coach. The initial outlay can also be reduced by using mass-produced pressings instead of the chamfered profiles originally used, which on account of the small number of parts were employed in order to avoid tool expenses. It will be possible to replace hand rivetting by machine rivetting, and also to reduce the labour charges, when the shop has been provided with suitable tool equipment and the men have become familiar with this kind of work.

The primary question, however, was to find the most satisfactory solution from the constructional point of view, namely the strongest and at the same time the lightest construction; this meant creating the counterpart of the

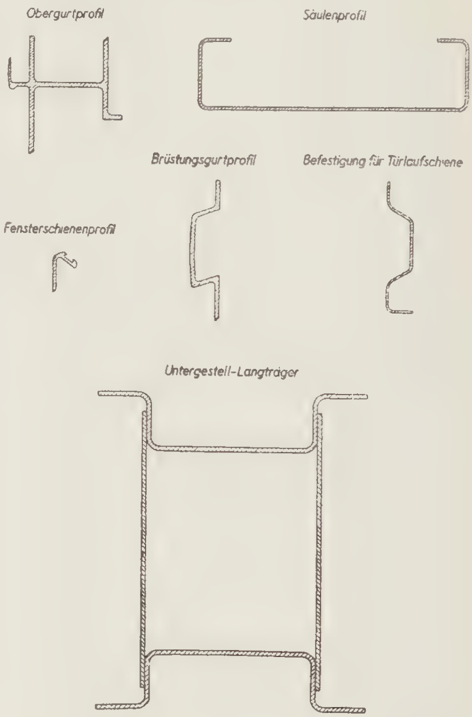


Fig. 2. — Light metal sections.

Note. — Obergurtprofil = top flange. — Saülenprofil = pillar. — Fensterschienenprofil = window guide rail. — Brüstungsprofil = waist rail. — Befestigung für Türlaufschiene = fastening for sliding door guide rail. — Untergestell-Langträger = solebar.

many constructional methods which have hitherto been in vogue.

Constructional material.

For the constructional material, a metal which is particularly capable of resisting mechanical stresses and corrosion was adopted, namely hydronalium, an alloy of aluminium and magnesium. Magnesium found in Germany in unlimited quantities, may reach a proportion of 12 %. For those parts subjected to considerable stresses, such as the frame, axle guards, headstocks and body sides, the choice fell on semi-hard Hy. 7, having a tensile strength of 35 to 38 kgr./mm² (22.2 to 24.1 Engl. tons per sq. in.), corresponding to that of « 37 » steel, and a fatigue strength of 12 kgr./mm² (7.6 tons per sq. in.); for the other beams, use was made of Hy. 5, semi-hard, with a tensile strength of 29 to 31 kgr./mm² (18.4 to 19.7 tons per sq. in.), on account of the lower price, and for the panelling and other parts made of sheeting, semi-hard Hy. 25, with a tensile strength of 22 to 25 kgr./mm² (14.0 to 15.9 tons per sq. in.) for the same reasons as those above, but also in particular because it is not the tensile strength which matters, but rather — on account of resistance to warping necessary for the solidity of the side walls — the modulus of elasticity E which is the same for all light metals with an aluminium basis, and goes up to approximately 700 000 kgr./cm² (9 950 000 lb./sq. in.), the modulus of elasticity of steel being 2 100 000 kgr.cm² (29 900 000 lb./sq. in.), i. e. three thimes that of light metal; the result in that for equal sections all the elastic deformations taking place in constructional parts made of light metals are approximately three times greater. But if, for example, for reasons based on the number of vibrations and connected with the phenomena of resonance, it is desired that the deformations shall not be greater than those occurring in steel, the moment of inertia of the part in question must be increased approximately threefold. However, this measure must not necessarily result in a greater weight. Even in the most unfavourable case, that of prismatic bars, the light metal still has an important advantage from the point of view of the weight, because it is known that the weight only increases linearly with the height, whereas the moment of inertia is proportional to the cube of the latter.

This has another result as well, namely that such a material as, for example chrome-molybdenum steel, which has a high tensile strength but whose modulus of elasticity does not attain a value corresponding to the increase in tensile strength, cannot often be fully taken advantage of in thin plate construction, such as the panelling, and therefore in this respect is not much better than ordinary steel as regards weight. On the other hand, light metal is better than ordinary steel on account of its lower specific weight, because it is only necessary slightly to increase the thickness of the plates in order to get the same local stiffness as with steel.

Corrosion.

The constructional materials subject to corrosion, either at the lap-joints or on the inside faces of the box-beams received a double coat of a special varnish for light metals which has already been successfully used in aeroplane construction. As hydronalium in itself can be taken as corrosion free, the application of the two coats of varnish resulted in this immunity being still further strengthened. In addition, in order to eliminate the causes of corrosion, special attention was given to ensure that the condensation water forming in the empty spaces drained away immediately, by fitting pipes for discharging the water and air. Rainwater from the roof is led off in gutters arranged above the

windows and thence through pipes fixed in the walls.

Principles of construction.

To make the light-metal construction economical, in view of the appreciably higher cost of this material, it is necessary for the principle to be pushed to its utmost limit, and to do this by cutting out all superflous part or material, not by raising the maximum stress limits. An optimum light construction of this kind can be achieved by designing as far as possible, before assembling, the shape of each supporting element to meet the stress it has to withstand, by arranging for the load to be carried by the greatest possible number of constructional elements, and — thanks to a cleverly designed arrangement — eliminating as far as possible all the auxiliary beams which play no direct part in the general load carrying construction. Great care must also be taken to see that all the parts which by their nature do not help to carry the load, such as the brake, heating apparatus, and interior fitting out, are made as light as possible. As each pound of weight saved has to be paid for by an increase in the cost of using light metals, it is recommended in addition to reconsider the rational shape of all the parts, which hitherto have been continually embodied in one vehicle after another without any other thought being given to them, and which thus form in a manner of speaking part of the traditions of a designing office. In order to avoid any effects arising from reactionary tendencies, it was deemed necessary not to confide the treatment of the light-metal parts to the workshops which generally deal with steel parts, and for this reason Messrs M. A. N. established a special light-metal shop in which the light-metal profiles and plates were stored and machined, and in which the two hydronalium coaches were assembled. This light-metal shop appeared to be necessary for the particular reason that in those shops which work in steel, the skin of the light-metal parts might deteriorate, which is to be avoided, the light metal being more sensitive to scoring, and the iron filings lying about on the floors might leave bits in the light metal likely to give rise to electro-chemical corrosion. Special mention must be made of the conscientious and thorough way in which all the risks were foreseen and avoided, both in the hydronalium manufacturer's works and in the workshops where the vehicles were built.

Body.

Underframe. — The principal dimensions of the underframe are given in the plan and elevation in Fig. 3. The frame and body are formed of plates and sections made of hydronalium, and assembled by rivetting. The parts subject to wear by friction and those to which for lack of space it is not possible to give the necessary dimensions are of steel.

Whilst in the body of the coach, the position of the supporting framework is determined, generally speaking, by the lay-out of the vehicle, a greater latitude is possible in the constructional arrangement of the underframe.

When designing the latter, everything possible was done to choose the most suitable shape for each kind of stress met with. Above all, in order to obtain rational stress distribution systems, bent beams were in principle avoided because, by the change in direction of the stresses, they give rise to additional secondary and consequently useless stresses. It also appeared advisable to arrange a rigid frame for the chassis, not only for the purpose of ensuring the proper transmission of the tractive effort and impact stresses, but also to make it capable, by its rigidity in every direction, of absorbing all other stresses exerted on the frame, such as those transmitted by the springs, axle guards,

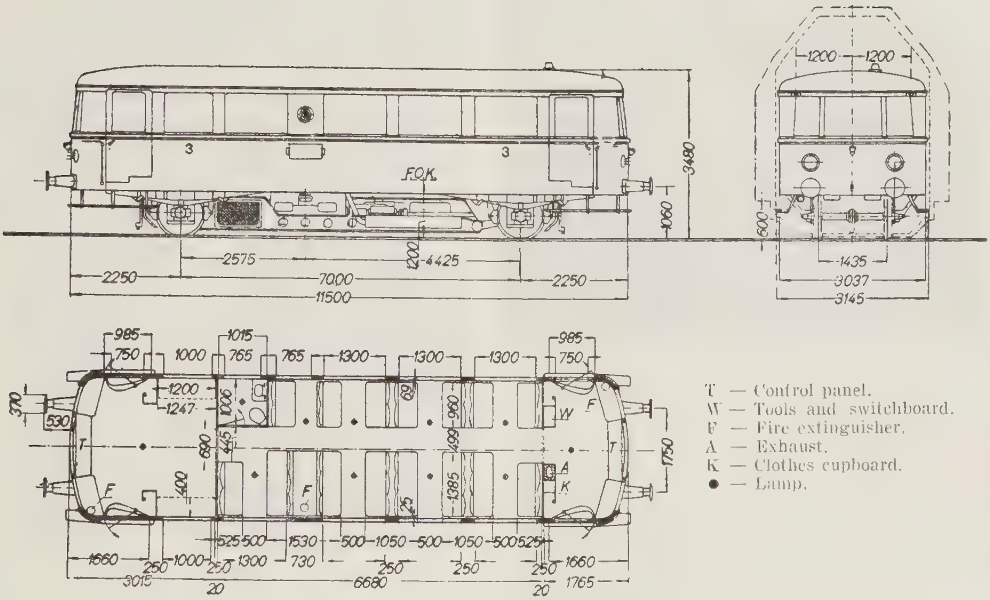


Fig. 3. — Plan and elevation.

life guards, brakes, etc. — and this no matter in what direction they are exerted. Hence the employment of two solebars shaped like box girders, passing above the centres of the spring buckles and offering great bending and torsional strength, the ends being connected with the buffer beams in the form of double-web girders, thus constituting an extremely efficient protection against telescoping, which enables the tractive and impact stresses to be reliably transmitted to the solebars (see fig. 4). The position of the solebars was determined with the consideration in mind that it was necessary in any case to go round the window bays, and that with the relatively short frame the statically exact deviation of the stresses to be absorbed by the buffers and the running gear, transferred for example in the plane of the side walls, would have necessitated too heavy a construction. On the other hand, in the plane chosen for the solebars, the points of application of the stresses enumerated above were almost concentrated, so that their « short-circuiting » was a relatively simple matter.

Fig. 4. — Headstock.

When designing the frame, special care was taken that the flanges of the beams should follow one another

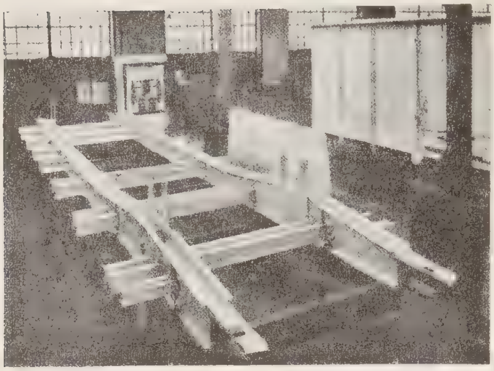


Fig. 5. — Underframe.

throughout without any interruption (see Fig. 5). For this purpose the flanges of the longitudinal and transverse beams which cross one another were placed in different planes. Consequently the flanges absorbing the major portion of the stresses are not weakened transversely nor bent at any point, with the additional result that there is no obstacle at any point in the path of the stresses. The intersection of the different beams takes place in their web, near the neutral zones, and therefore is to be found near the zones of lowest stress. At the door and window pillars the solebars are assembled by cross-bearers formed of chamfered plates of « Hy » metal, 2.5 mm. (0.1") thick. Between the main cross beams, auxiliary cross beams are also arranged, of « U » section, which are necessary for the trap-door holes in the flooring, to afford access to the engine from above. The trap-doors in the floor have wooden frames, lined with cork.

The method of construction with assembled parts enabled a stress of about the same magnitude to be obtained at all points, and also enabled the stress concentrations to be absorbed. Nevertheless, and although no plate is more than 4 mm. (0.157") thick, it was easily possible to reduce the maximum stress to 3 kgr./mm² (1.9 tons/sq. in.); in exceptional cases, only rarely occurring, 5 kgr./mm² (3.2 tons/sq. in.) has been admitted. This result is all the more remarkable in view of the fact that the practical results for light-metal vehicles are still unknown, and the stresses observed in aeroplanes are, after all, of such a different nature that the data obtained in that direction cannot be utilised just as they are in the construction of railway vehicles. In spite of the low stress on the constructional materials, it was ascertained after the vehicles had been completed, by comparative weighings, that the weight of the vehicular part of the hydronalium coach, contrary to all expectations, was about 43 % lighter than that of the light-steel vehicle built to the same dimensions. With this method of construction, particular care had to be taken with regard to the way the stresses were transmitted to the girders. At all these points, steel fittings were provided for spreading the stresses, which are exerted in places in a very concentric manner and frequently accompanied by friction, over the greatest assembling areas. In order to avoid all electro-chemical corrosion, these fittings were galvanised hot and covered with a coat of paint on the jointing surfaces when being put together. In addition the joints were made in such a way that all the individual parts of a built-up beam were stressed simultaneously by the stress to be absorbed.

The transfer of the stresses from the spring brackets to the solebars offered no difficulties of a constructional nature, the box-girders having been arranged perpendicular above the centres of the suspension springs; moreover, with a view to obtaining an improved degree of strength in the fittings their fish-belly shaped flanges were turned to the underside (see Fig. 6).

The axle-guards, made of forger Hy7

Fig. 6. — Solebar.

25 mm. (1") thick, were also connected, organically in each case, with one of the solebar flanges. The stresses acting transversely on the axleguards are taken up by struts, so that the axleguards are only normally stressed under compression. But as, after each deflection of the springs of the body of the vehicle, an additional moment is produced which must be absorbed by a box-girder, the rigidity of which is opposed to the torsion, it was necessary to fit the body with panels for spreading the couple throughout all the walls.

As the construction of the frame did not lend itself to the application of the load at a single point, special precautions are necessary for lifting the body.

Flooring made of corrugated sheeting. — The use of diagonal connections in the underframe was abandoned. On the contrary, the whole of the frame was covered with corrugated sheeting, proof against shearing action, which at the same time had to serve as a connection between the side wall and the solebar in such a way as to confer on this latter the role of lower member, out of centre it is true, of the side walls. As, for constructional reasons, it was necessary to arrange the corrugations in the direction of the cross-bearers, it was obvious that they could be made to serve as top flange of these latter, which was realised by a plate web interposed between these constructional parts. It is true that this arrangement had the effect of doing away with the real top flange of the cross-bearers. Moreover, with the plate web, the parts situated in the neighbourhood of the stressed zone were not interrupted in line with the solebars, but passed above them (fig. 7).

Body-work. — Between each pair of window bays there is a one-piece pillar, covered up below the waist rail by the panelling, but visible in its top part. In this way, a more economical arrangement was obtained, since it was no longer necessary to do any shaping of the side wall plating. The upper flange is a one-piece pressing, designed so as to be capable simultaneously of fulfilling the largest possible number of conditions, namely : connection between the side wall pillars and double flanged

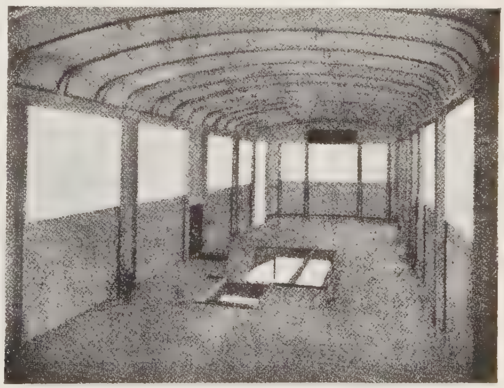


Fig. 7. — Corrugated plate flooring.

roof sticks, housing for the guttering, and connection for the luggage rack brackets.

The roof sticks consist of « V » shaped drawn sections only 1.2 mm. (0.047") thick; the roof sheeting is 1 mm. (0.039") thick. The roof forms a prolongation of the side walls and is so arched that the free space is used to the best possible advantage for the stowage of luggage. With a view to ensuring sufficient resistance against shearing, the plate panelling of the side walls had to be made 2.5 mm. (0.098") thick, which side walls, as already explained, only go up as far as the waist under the bays. The sheathing of the end portions of the vehicle is formed of hydronalium plates 1.5 mm. (0.059") thick.

When the loading tests on the body were being carried out, it was noticed with surprise that when the load was first applied there was a certain slipping movement which continued until the rivets had made full contact. Afterwards, whilst the load was being increased to its maximum (100 % increase on the load representing the passengers, with 30 % increase for the dynamic actions), the deflection was still hardly noticeable, and therefore remained lower than that for the corresponding steel coach, which is surprising with this modulus E, but is explained by the fact that every part of the construction is effectively called upon to do its share in carrying the load. After the tests, the body of the vehicle resumed its initial position.

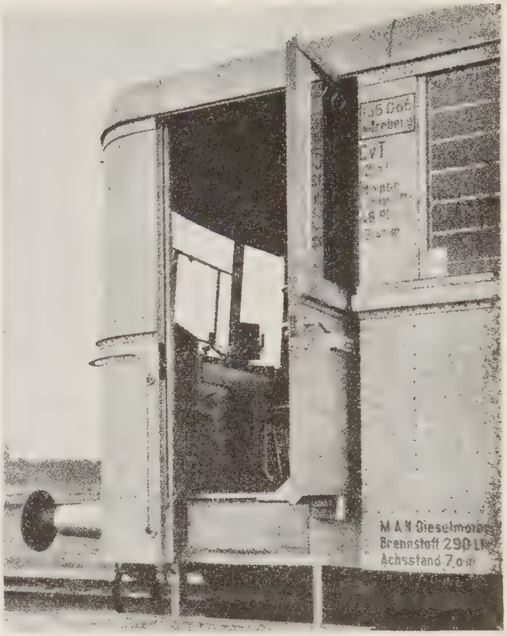


Fig. 8. — Entrance door.

Doors (see fig. 8). — The entrance doors were designed on a system patented by the Waggonfabrik Wismar, in which the axis of rotation is obliquely carried back towards the interior; in this manner, in spite of the larger interior dimensions, the open doors do not project beyond the loading gauge limits, with the result that it was not necessary to reduce the width of the vehicle in line with the doors, which are thus flush with the side walls; this is a particular advantage in the construction of fast-running coaches from the point of view of air resistance. On opening, the doors are partly engaged in a recess arranged in the entrance at a certain angle to the wall of the coach, while the other part remains outside the body. Another advantage of this method of construction is that neither the side wall nor the flooring are weakened in this part of the vehicle, which is generally subjected to heavy fatigue, whilst with sliding doors this drawback, due to the small cross section of the door pillars or to deviations of forces, is inevitable. At each entrance there are two footsteps; the top step is placed on a level with the bottom edge of the body. The bottom step, to enable the train staff to pass into the trailer, is located near the front end of the buffer casing. The footsteps are

made of hydronalium, and covered with a chequered rubber mat. When the door is closed, the top step is covered with a hood carried on the door. The doors have droplights operated by means of straps.

Running gear.

Bochumer-Verein light wheel sets, carrying and driving, were employed, the characteristics of which are that they have hollow chromium-nickel steel axles and light corrugated steel wheel centres of the Ürdingen type. The tyres are 50 mm. (2") thick, and the diameter over the tread is 900 mm. (2' 11 1/2"). The axle-journals are 90 mm. (3 9/16") in diameter, and they run in double roller bearings of the *Kugelfischer*, Schweinfurt, type. For the axlebox covers and the distance rings in the double roller bearings *Electron*, insulated with *Novotox* to prevent corrosion, was used, whilst the boxes themselves are of cast steel, with the object of avoiding the risks resulting from hot boxes.

As in the case of the light bodies which do not carry the weight of the driving equipment the overload factor is relatively very high — the ratio of the useful load to the tare is almost equal to unity for the hydronalium coach — the suspension spring, which is too rigid with the admissible deflection of 100 mm. (3 15/16") under the empty vehicle, must be capable of being adjusted, and its characteristic must approach as nearly as possible a given logarithmic curve [see Herr Brauer's article, *Aluminium* 37, No. 5, « Strassenfahrzeuge aus Leichtmetall » (Road vehicles made of light metals)]. This was done by means of a suspension system of the M.A.N. type, in which a 7-plate spring, with an extended length of 1 600 mm. (5' 3") is combined with a special indiarubber spring (see fig. 9).

This latter consists essentially of a rubber ring with inside and outside

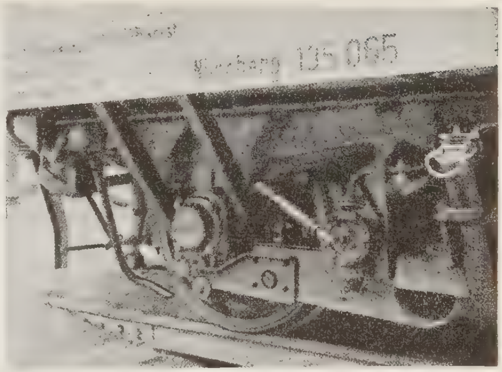


Fig. 9. — Running gear.

shell surfaces on steel rings, in a manner similar to *Silentblocks*, with the fundamental difference that the efforts applied by the steel rings stress the rubber in shear. Consequently this arrangement not only has the effect of minimising the transmission of noises arising from metal parts such as the rails, wheels and brakes, but also of obtaining a resilience in the rubber spring otherwise only possible with a much larger quantity of rubber, entailing an undesirable length of the hanger pin.

The rubber spring works under normal load, and its total deflection is 25 mm. (1"). If the useful load is increased more than this, the rubber spring is pressed home on a rubber compression spring, which then allows nothing more than small deflections. The laminated spring, on the contrary, works throughout the whole range of loads, and under the useful load undergoes a maximum deflection of 70 mm. (2 3/4"). As under the empty coaches, the special rubber spring is only subjected to a stress of 4 kgr./mm² (2.54 tons/sq. in.) a long service life can be expected from it. In order to make clear the effect of the rubber springs beyond all doubt, the second hydronalium coach has none.

This special rubber spring was also

intended at the same time to ensure improved running of the vehicles fitted with radial pairs of wheels of the *Verein* type, since the hanger pins are rigidly fitted inside the interior steel box and all movement of the axle, which is perfectly free to move in every direction, is absorbed by compression of the rubber. As was expected, the running of the coach was remarkably smooth during the trial trips. Owing to lack of sufficient data with regard to the life in service of the special rubber springs, attention was paid during construction to see that renewals of the shear spring could easily be carried out in service.

Brakes.

The construction of the brake in its traditional form necessitates a very large number of fastening points for the brage gear to the underframe. As, with the single cylinder system, the fastenings are called upon to absorb stresses which are at times considerable, it would have been necessary for the underframe (which offers great resistance as a whole, it is true, as the result of the method of construction used, which though rational does not present the same local rigidity as a framework made up of rolled sections), to be fitted with a very large number of auxiliary parts not required for carrying the load, which would also have made the driving equipment housed in the frame less accessible.

In order to procure the greatest possible weight saving, it therefore appeared expedient to lengthen the air pipes and consequently shorten the brake rigging; this result was obtained by substituting four cylinders, each directly acting on a carrying wheel, for the single light-metal brake cylinder towards the middle of the coach. This resulted in four independent steel brake riggings suspended by two bolts only from the torsion resisting solebar, with *Silentblocks* interposed for insulating the body against disagreeable brake noises. This arrangement provided a surprising simplicity in the brake riggings as well as an exceptionally straightforward general arrangement of the underframe.

As a complement to this system, a *Teves* (Frankfort) hand oil-pressure brake, capable of being operated from each driving compartment, was installed. The oil brake cylinders are fitted immediately under the compressed air brake cylinders, of which they form an integral part. The hand wheel of this brake is made of cast silumin and is removable. The large weight reduction of the vehicle and the corresponding diminution in the kinetic energy would have justified the substitution of brake shoes capable of taking 25 mm. (1") wear for those of 40 mm. (1 9/16") wear; but for service reasons, this measure was not adopted. The life of the brake shoes is prolonged, since the heating and the wear of the materials are less for the much lighter coach. The brake shoes are screw-adjusted.

An undeniable drawback of this brake system is that between the *Hikpt* triple valve and the brake cylinders there is a larger space for air losses, and the number of possible leakages is increased, the piping being under pressure during braking. On the other hand, the following advantages may be quoted :

1. The weight is appreciably lower; the weight economy reaches 34 %;

2. The frame presents a more straightforward arrangement;

3. The slack is appreciably less, even with the use of Silentblocks;

4. In case a part of the brake rigging breaks, the vehicle still remains brakable at 75 %.

The sanders, provided for each wheel, are of hydronalium plates, 2 mm. (0.078") thick.

Draw and buffing gear.

As the railcar has only to haul a light trailer, the draw gear, made of steel, is of particularly light construction, but sufficient for a motor coach, and the designers were content to make the dimensions of the non-standard parts agree with the actual stresses. The heads and plungers of the light buffers are of steel, whilst the buffer casings are of cast electron, with steel insertions at the points subjected to wear. They are of conical shape, which gives them greater resistance to transverse forces.

Arrangement of the driving equipment.

In order that the body of the vehicle may be freed from the weight of the driving equipment and efficiently protected against the vibrations from the motor, a special carrying frame was designed for this equipment, mounted on the axles. In accordance with an arrangement patented by Messrs M.A.N. the boxes hitherto used for the driving axle were employed, whilst the carrying axle is provided between the wheels with a special oscillating bearing, the purpose of this three-point suspension system being to avoid stress disturbances and additional deformations of the carrying frame.

It might be thought that this arrangement, comprising a carrying framework which projects beyond the wheelbase by 7 m. (23') would be heavier than the usual arrangement; this is not so, because the body of the vehicle may be of lighter construction, and moreover the many auxiliary arrangements necessary for housing the radiators, fuel tanks, accumulators, etc... are done away with. The rational grouping of the driving equipment has very largely contributed to making the arrangement more straightforward and more accessible.

The carrying framework is made up of welded steel plates. By using corrugated plate cross-bearers and torsion pipes, the conditions connected with the different modes of stress have been satisfied, and consequently not only was a lighter construction obtained, but at the same time a construction capable of ample resistance, as was proved when the comparative loading tests were carried out.

Heating.

The heating apparatus, of the M.A.N. type, utilises a portion of the heat contained in the diesel engine cooling water which would otherwise be dissipated through the radiators, for heating the compartments of the vehicle. The engine exhaust gases afford an almost equal amount of heat which could be used for this purpose; but a heating plant fed by the cooling water has the fundamental advantage that on account of the large amount of heat contained in the cooling water. the fluctuations of the load on the diesel engine have a less rapid repercussion on the heating of the coach; in particular whilst the diesel is idling, the cooling water is still capable of supplying heat for a certain period, which is not possible with heating apparatus using the exhaust gases except by throttling the flow of the gases.

Heating by the cooling water is in any case more reliable in operation, and is not attended by the disadvantage inherent in heating by the exhaust gases that in case of defects in the piping, the exhaust gases may penetrate the coach interior.

Unlike the systems used hitherto, in which the cooling water circulates in the interior of the coach in special coils or in radiators, the M.A.N. apparatus is based on the simpler conception of introducing the fresh air, heated by the diesel engine radiators, into the coach interior. The results are that :

1. The piping becomes appreciably simpler and lighter;

2. The heating in more rapid in ac-

tion, as the pipes carrying along the heat at low speed, i. e. in this case the water-tubes, are of very short length;

3. The heating is effected by the warming of fresh air.

All the same, with equipment of this kind it is necessary to have two radiators which are independent one of the other — also from the point of view of the air circulation — so that by avoiding the throttling of the air flow, the full output of a radiator can be used during the critical transition period, when the other radiator is working for the heating of the interior of the coach and is only taking a fraction of its proportional quantity of heat from the engine cooling water, since the heating of the vehicle can only absorb about 10 % of the total quantity of heat present in the cooling water.

Control of the quantity of air drawn in, in order to regulate the temperature of the heating air — but not the temperature of the cooling water — is ensured by throttle valves fitted in front of the radiator. The air distribution valve, fitted behind the radiator, directs the heated fresh air into the distribution chamber, so that the air does not possibly escape to the atmosphere but passes through a filter into the coach interior. Heating ducts sheathed with insulating material, laid between the outside wall and inside panelling and bent only at the pillars under the seats, ensure the uniform heating of the coach at a comfortable temperature. If necessary heating of the fresh air can be replaced by heating of the circulating air. In this case the air supply is not drawn in from outside, but from the coach interior, after the throttle valve mentioned above has been completely shut off. By reason of the considerable excess of heat available, this alternative solution was abandoned for the time being.

The results obtained up to the present have come up to expectations and are satisfactory from the air conditioning point of view. The new light-metal accessories required by the engine cooling plant weigh about 25 kgr. (55 lb.).

Interior equipment.

Lay-out of compartments. — The railcar is divided into three compartments, namely : two driver's compartments at the ends, one of which is extended into a luggage compartment, and in the middle a passenger compartment with 36 seats (see fig. 10). In addition, 14

Fig. 10. — Passenger compartment.

more passengers can be accommodated in the driver's compartments. When the folding seats in the luggage compartment are turned up, four bicycles can be suspended on carrying hooks. In addition, a certain number of chests are fitted in the compartments, in which accessories needed en route are kept in proper order; these chests were arranged in such a way as to contribute to the stiffening of the construction. The fitting of a double partition between the passenger compartment and driver's compartment was considered necessary for housing the exhaust pipe, and also the noise dampers fitted as the result of the latest researches on this subject, but which take up much room. The cupboard and

cooking utensils for the driver are also arranged in this space. Moreover, it was deemed desirable to clearly arrange the electrical control gear, and it was therefore fixed in a place easy of access to eye and hand.

Sheathing. — The use of a corrugated plate floor was only possible when a suitable, extremely light and very elastic filling-in material in the form of well-expanded cork had been found. For fixing the cork in position, shaped strips were fitted in the corrugations and on these strips an adhesive with a bitumen basis was applied, then a mat of the same material was stuck on top, and finally a covering of 5 mm. (3/16") thick plywood and linoleum fitted. It was found that this flooring was not only very well insulated against cold and noise, but that it was decidedly elastic to the tread, which made it pleasant to walk on.

In order to prevent continuous droning noises, sound-deadening material was glued on the side wall plates. This was purely a preventive measure, because no noise of any intensity — we are not alluding to the accidental loosening of a panel plate under sudden thermal action — has been noticed up to the present, no more than on the light steel vehicles. Nevertheless this arrangement has also helped to protect the coach interior from outside noises. From the sound-proofing point of view, great progress has therefore been achieved with this vehicle, particularly as the result of using the type of flooring described above, and also the new type of silencer used as a sound filter for the exhaust pipe and exhaust nozzle.

For sheathing the side walls, panels of plywood, 4 mm. (5/32") thick were used, covered with a veneer of polished elm with a matt finished surface. The ceiling was covered with 3 mm. (1/8") thick plywood painted a greyish-white, on which, in line with the luggage racks, *Resopal* was glued to avoid scratches. For fixing the wooden sheathings, new methods were sought in order to do away with the use of filling pieces, which are very heavy; the plywood was therefore attached by means of screws screwed into special nuts rivetted to the pillars. In some cases also, in order to avoid cumbrous joints, use was made of the method of rabbetting and inserting, for example, the closely jointed pieces of plywood for the sheathing of the roof in grooves of double « T » sections, and simply screwing these latter on to cleats.

For the framework of the doors and windows, formed of plywood, instead of heavy wooden mouldings, light-metal sections were used, which resulted in a saving in weight and an improved appearance. Moreover it was deemed desirable to seek a new solution on account of the deterioration of the varnish applied on the pieces of wood, under the effect of water infiltration.

Windows. — This was why the windows were given closed metal frames which could be introduced into guides made of *Riloga*. For the window lifts in the passenger compartment, turn-handle gear of the *Waggonfabrik Busch-Bautzen* type was employed, this being particularly light and enabling the window pane to be raised in 8 turns. Fixed windows are fitted in the coach ends, in the luggage compartment, and in the coupé next to the lavatory compartment. The bottom part of the window in the lavatory is fixed, and the top part can be hinged back towards the interior. The windows in the driving compartment are of 6-mm. (1/4") thick *Securit* glass, and the other windows 4 mm. (5/32") thick plate glass. In the passenger compartment there are rust-coloured curtains reaching down as far as the waist rail and sliding in the Riloga rails.

Partitions. — To increase the trans-

verse stiffness of the body and reduce the weight, the partitions were made of 2-mm. (0.079") thick plates. Single or double partitions are used according to whether stiffening was necessary or not, and could be covered up if necessary. On the passenger compartment side, the plates were covered with plywood boards. In the second railcar built of hydronalium, the partitions were constructed as usually, with plywood panels, to enable the advantages and drawbacks of the two methods of construction, and also the difference in cost and weight, to be ascertained.

In the partitions on the luggage compartment side there is a swing door, and on the opposite side a sliding door made of plywood is fitted. To stress the technical nature of the driving compartments, the plate construction was purposely accentuated and the rivet-heads left visible. These cabins are painted with green oil paint, to enable them to be easely cleaned, and the paintwork renewed at low cost.

Seats. — The seat frames are formed of light-metal welded tubes. So that the space under the seats can be used as extra stowage room for luggage, the number of legs was reduced to 4, even for the six-seat benches, and the construction of the seat frame was made rigid enough in itself, to make the usual fastenings in the compartment walls unnecessary. These benches are extremely light in weight, only 3.1 kgr. (6.8 lb.) per seat.

The weights of a few types of seating benches per passenger seat are compared in the table hereafter.

	Tubular frames made of			
	hydronalium		steel	
	kgr.	*lb.*	kgr.	*lb.*
Fibre seats	3.1	*6.8*	6.1	*13.4*
Lightly upholstered, plush covered. . . .	8.0	*17.6*	11.0	*24.3*
Lightly upholstered, leather covered . . .	8.2	*18.1*	11.2	*24.7*
Webbing seats	3.5	*7.7*	6.5	*14.3*
Wooden slat seats. . .	6.9	*15.2*	9.9	*21.8*

The long double seating bench, for six passengers, fitted over the diesel which projects into the passenger compartment, is in sections. Two seats are fixed and there is a small cupboard between the backs. The remainder of the double

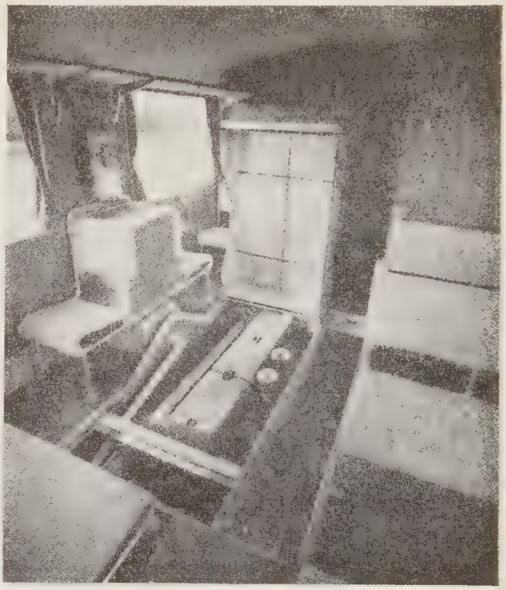


Fig. 11. — Tip-up seat over engine.

seating bench contains in the bottom a bonnet made of plating for the engine; the bench can be raised, and in this position gives convenient access to the driving equipment (see fig. 11).

Fittings. — All the fittings, such as door handles, clothes-hooks, also all kinds of plates are, of course, made of light metal. Since these parts were designed for the hydronalium railcar, their use has spread rapidly for coach construction, on account of the possibility of using national products and thanks to their low weight. By suitably treating the surfaces, resistance to corrosion — through they are already sufficiently corrosion-proof in themselves — can be increased, and the hardness of

the surfaces appreciably increased by producing thereon a finish resembling corundum; it is also possible to obtain the most varied of metallic shades, so that all tastes can be satisfied. The initial difficulties have been overcome by redesigning the shapes of the light metal fittings to suit the new material. Recently the cast fittings have been replaced by pressings, because in this way greater strength is obtained with less material, with the result that the breakages of luggage rack brackets, clothes hooks, and other fittings subjected to heavy wear and tear in service only rarely occur. The luggage racks are made of cast hydronalium; at each bottom corner there are two cast-on clothes-hooks. The front edges of the luggage rack brackets are joined together by light metal angles into which the luggage net is threaded. On the wall side, the luggage rack is fastened to a flange of the section forming the roof stick. The use of longitudinal luggage racks instead of transverse racks has resulted in a weight saving of 64 kgr. (141 lb.).

Control table. — This was arranged in the middle of the driver's compartment so as not to impede passengers getting in and out. The driver sits in front of the table. To enable him to get as near the panel as possible, and leave as much room as possible, the control panel has a knee-hole like a desk. As the rear driver's compartment is available for passengers in case of need, the panel is covered in with a hinged board, which can be turned over to one side where it serves as a desk for the driver. The folding seat is lightly padded and leather covered, and is turned up into the gap under the panel when not in use. To prevent dazzle, the driver's compartment windows are slightly inclined towards the interior like the coach ends. On each side of the ends two headlights with removable discs are fitted. On either side of the control panel there is

Fig. 12. — Driver's compartment.

a small bench with chests underneath (see fig. 12).

Lavatory compartment.

The partitions of the lavatory compartment are formed of double sheets of

Fig. 13. — Lavatory.

hydronalium 2 mm. (0.079") thick. In this compartment there are besides the closet hopper, a mirror, a wash-bowl, and two water cans made of hydronalium. The floor is laid with a *Getefo* rubber covering, 6 mm. (1/4") thick. The cantrails, floor rails and lavatory door frame are made of light metal. The discharge pipe is also of hydronalium (fig. 13).

Use of electron.

In addition to the parts already mentioned, electron was used for all mouldings, such as swing-door rails, safety bracket for spring, fan bearing with nozzle, and gearbox. The oil cooler is also made of electron.

Exterior painting.

For reasons of economy both of weight and cost, and by way of experiment, there was no special painting of the body of the coach. However, the engine carrying frame, and all parts below the bottom edge of the body, as well as the inscriptions on the coach, were painted a steel-blue colour. Before being assembled all parts had two coats of paint applied on their contact surfaces.

Comparative weights.

The following table gives a comparison of the weights of the hydronalium railcar and of the light-steel railcar, and shows the different weight savings obtained :

Weight in kgr. *(in lb.)*

	Light steel railcar.	Hydronalium railcar.	Difference.
Railcar in working order	16 300 *(35 930)*	12 300 *(27 115)*	— 4 000 *(— 8 815)*
Complete body	10 245 *(22 580)*	6 550 *(14 440)*	— 2 695 *(— 5 940)*
Driving equipment, complete, with wheel sets and axle-boxes	6 055 *(13 345)*	5 750 *(12 675)*	— 305 *(— 670)*
Underframe, axle guards and spring hangers.	2 005 *(2 755)*	1 165 *(2 570)*	— 840 *(— 185)*
Body frame	770 *(1 695)*	625 *(1 375)*	— 145 *(– 320)*
Plate panelling	750 *(1 540)*	225 *(495)*	— 475 *(— 1 045)*
Draw gear	70 *(150)*	60 *(130)*	— 10 *(— 20)*
Buffing gear	200 *(440)*	135 *(295)*	— 65 *(— 145)*
Entrance doors	225 *(500)*	245 *(540)*	+ 20 (*) *(+ 40)*
Flooring	795 *(1 755)*	230 *(510)*	— 565 *(— 1 245)*
Partitions, interior side walls, lining of ceiling, and inside doors	565 *(1 250)*	470 *(1 040)*	— 95 *(— 210)*
Interior fitting-out	3 235 *(7 130)*	2 380 *(5 245)*	— 855 *(— 1 885)*
Brakes	1 380 *(3 040)*	865 *(1 905)*	— 515 *(— 1 135)*
Paint	250 *(550)*	100 *(220)*	— 150 *(— 300)*

(*) Instead of the 4 swing doors fitted in the hydronalium coach, the steel coaches have 2 swing doors and 2 sliding doors, all of them made of light metal, which explains their lower weight.

The great weight saving obtained is due primarily to the extensive use of hydronalium and electron; but it is also partly explained by the fact that each part was adapted to conform with present-day technique and that the constructional parts were further improved when and where necessary, giving rise to a number of novel features.

These two hydronalium railcars, the initial expenditure on which was appreciably higher than that on the steel railcars built for comparison, are experimental vehicles. It will only be possible to procure reliable and accurate data about the economic value of vehicles of this type after trial runs over a long period; nevertheless, the construction of these railcars has already brought to light valuable information regarding the weight savings obtained. This fact may be of decisive importance for vehicles intended for mountainous districts or where owing to competition, rapid acceleration when starting is required, especially when, as in the present case, the efficiency figure of 9.5 for the steel cars rises, by reason of this fact, to 12.7 for the hydronalium cars, an increase of about 34 %.

[625. 142.2 & 625. 142.5]

Steel or wood sleepers ?

by Oberbaurat LEONHARD, retired Abteilungsdirektor, Breslau.

(From *Gleistechnik und Fahrbahnbau.*)

1. History and Statistics.

Transverse sleepers, acting as strong cross stays or tie bars, to keep the rails firmly in their proper relative positions, thus ensuring the correct maintenance of the gauge are universally employed at the present day to carry the rails on railway lines. By spacing the sleepers further apart or closer together, and by varying their length, they may be adapted to the different conditions of load and stress to which they are subjected, and they allow of satisfactory drainage of the permanent way being obtained.

When railways were first constructed in Germany, in 1835, wood was exclusively used for sleepers, oak being preferred at first, owing to its toughness and ability to resist deterioration. In due course, however, difficulties due to the rapid development of the German railway system were encountered in using oak exclusively and pine woods had to be more and more resorted to, especially as the constantly rising price of oak sleepers considerably increased the cost of railway construction.

The rapid deterioration of soft wood sleepers, due to decomposition provoked by fungoid growths, made it necessary to impregnate sleepers with rot resisting materials in order to increase their life, and this process was gradually applied to oak sleepers also.

The first general statistics covering the working of the railways in Germany appeared for the year 1880/1881. These lines then had a total length of 57 321.46 km. (35 620 miles), of which 38 818.25 km. (24 120 miles) were State railways. From these statistics it appears that for the 2.41 million new wood sleepers, used on track alterations and renewals in that year, oak was still being employed to the extent of 58.2 %, the remaining 41.8 % being of pine. Of the oak sleepers 56 % were impregnated, while 85.7 % of the soft wood variety were so treated.

As the impregnation processes were improved, and especially with the adoption of pure creosote, on the one hand, and the use of sufficiently large sole plates to carry the rails, and coach screws instead of dog spikes, on the other hand, a considerable increase in the life of soft wood sleepers was obtained, the consequence being that, in spite of the increased loads to which the track was subjected, the use of soft wood sleepers instead of the dearer hard wood type became more and more common. During the period for which statistics are available down to the year 1913, the last before the world war, the proportion of new soft wood sleepers laid down reached its highest figure, 78.4 %, in 1900. In 1913, the proportion of hard and soft wood sleepers was 28.7 and 71.3 % respectively for a total number of 4.87 millions.

From about 1883 onwards the beechwood sleeper supplanted the oak one to a rapidly increasing extent, after it had proved possible to impregnate it completely with creosote and render it proof against deterioration through rot. Of the new hardwood sleepers used in 1913 21.0 % were of oak and 79 % of beech.

The regular compilation of railway statistics was interrupted by the world war, making a comparison with pre-war years impossible. The figures for the

years 1916 to 1920 inclusive do not contain the tables Nos. 6 and 9 dealing with the permanent way, and losses of territory made no inconsiderable change in the German railway system. The economic conditions of the post-war period also adversely affected the obtaining of the necessary materials required for regular track maintenance work. In the last volume issued of the railway statistics — for 1936 — in which no distinction is made between oak and beech in the particulars concerning hardwood sleepers, it appears that the proportion of hard to soft wood sleepers on the German State Railways was 44.1 and 55.9 %, in ordinary track, and 48.1 to 51.9 % for points and crossings.

During the rapid development of the German railway system in the eighties, which gave rise to a growth in the total mileage of about 15 000 km. (9 300 miles) or 26 %, the type of wood sleeper permanent way then used proved unable to meet the increased stresses imposed on it. An increased use of soft wood sleepers gave rise to difficulties, such as failure to maintain the gauge accurately, especially on curves, and rapid mechanical deterioration and wear. These results occurred all the more as the impregnation process then used afforded insufficient protection against chemical deterioration by rot. Attempts to overcome these defects were sought in the use of steel sleepers, which had already been introduced in the seventies, and were expected to give longer life and more accurate maintenance of the gauge.

In the working year 1880/1881, the amount of new steel sleepers used in the permanent way alterations and renewals came to some 14 %, so that of the total mileage then existing, approximately 57 321 km. (35 620 miles), there were 52 176 km. (32 420 miles) or 91 % on wood, and 1 310 km. (814 miles) or 2.4 % on steel sleepers. Of the remainder, 3 298 km. (2 049 miles) were on steel longitudinal sleepers and 423 km. (263 miles) on stone blocks. From then onwards the use of steel sleepers steadily increased at the expense of wood. Of the new sleepers laid in 1913, 36.9 % were of steel. The principal State Railways making up the German System which used steel sleepers exclusively, both for ordinary track and under points and crossings, were the Prusso-Hessian and the Würtemberg. The Baden State Railways changed over in 1881 to an almost exclusive use of steel, but the Saxon State Railways adhered to wood down to their incorporation in the German State Railways (Reichsbahn). The statistical volume for the year 1936 showed that the proportion of iron and wood sleepers on the German State system, with a mileage of approximately 48 906 (78 705 km.), was 33.3 % and 66.7 % for ordinary through track and 62 % and 28 % for points and crossings respectively.

According to an inquiry instituted in 1935 by the Studiengesellschaft für Holzschwellenoberbau (Association for the Study of Wood Sleepered Permanent Way), the results of which were published in the journal « Die Holzschwelle », Greece, Switzerland and Turkey were alone in Europe in having hitherto used steel sleepers on a large scale. Of the remainder the majority used wood exclusively, and a few steel to a small extent.

2. Advantages and disadvantages of the different materials.

The question as to which of the two kinds of sleeper should be given preference is still a debatable one. Not only technical but national economic reasons play a decisive part in it; the decision is as much influenced by the personal attitude of the railway engineer concerned as by the interest of the industries involved in the matter — steel production, timber and creosote trades and forestry interests. It is at least certain that, as shown from the results of

the above mentioned inquiry, the wood sleeper finds by far the greater use and is therefore preferred. The inquiry showed indeed that out of 242 783 km. (150 860 miles) of track about 230 600 km. (143 290 miles), or 95 %, were laid on wood sleepers and about 11 920 km. (7 410 miles), or 5 %, on steel sleepers. It is particularly interesting to note that the two countries, Belgium and Great Britain, possessing an extensive steel industry, but poor in timber, yet employ wood sleepers on their heavily loaded lines almost exclusively. Although the inquiry did not extend to Russia and particulars were wanting concerning France and Spain, the above-mentioned conditions remain little affected thereby, as it is well known that these countries prefer to use wood.

The advocates of the steel sleeper put forward as its advantages the better maintenance of the gauge and greater resistance to lateral displacement of the track, especially on curves, with consequent greater safety and also longer life. This opinion is not generally confirmed by experience obtained up to the present, which proves that it is possible, with suitable construction, to build wood sleepered permanent way able to meet all requirements in perfect safety. The proof of this lies in the fact already mentioned that the overwhelming majority of European lines are laid on wood sleepers, and that the German State Railways, acting on the decision made in 1928, has adopted the K type permanent way, laid throughout on wood sleepers, for the most important lines traversed by high-speed corridor trains and for the first-class lines traversed by the long-distance international corridor expresses, and that even the steel sleepered track laid in recent times is being converted to the wood sleepered type to allow this measure to be systematically carried out.

Unlike the practice with wood sleepers, the form of which has remained the same from the beginning, the shape of steel sleepers has undergone continuous change, as it was constantly found that the form in use at any given time did not suit the increasing demands of the traffic. The question cannot yet be regarded as settled. Though the steel industry may put it forward as an advantage that the use of steel enables any shape desired to be easily obtained, it must be objected in reply that any change of shape raises the cost of production and makes it difficult to standardise the track appliances and obtain materials for it economically.

In order to compete with the cheaper wood sleeper, attempts were made at first to reduce the weight of the trough shaped steel sleeper by cutting down the cross section and the thickness of the walls. The result of this endeavour was that these light-weight sleepers were very soon found unable to meet the requirements of the traffic, as they did not ensure a firm foundation for the track and deteriorated prematurely. It was thus found necessary te enlarge the cross section and to some extent to increase the thickness of the walls, which considerably raised the weight. During its development down to the time of the introduction of the German State Railways' design of permanent way, the breadth at the foot increased from 210 to 232 mm. (8.27 to 9.13 in.), the depth from 60 to 100 mm. (2.36 to 3.94 in.) and the cross sectional area of the trough shaped space from 82 to 122 cm^2 (12.71 to 18.9 sq. in.), without, however, reaching the breadth of 260 mm. (10.24 in.) and depth of 160 mm. (6.23 in.) attained by the wood sleeper. The weight correspondingly increased from 40 to 70 kgr. (88 to 154 lb.).

A typical example of how soon a design of steel sleepered track, which had been expected to give satisfactory economic results, can prove incapable of meeting expectations, is found on the Baden State Railways. The track laid

down in 1881, with steel sleepers of the Hilf form, 60 mm. (2.36 in.) deep weighing 42 kgr. (92.6 lb.), with a length of from 2.20 to 2.40 m. (7 ft. 2 5/8 in. to 7 ft. 10 1/2 in.) had to be removed from the main lines after a life of only 7 to 9 years, owing to the sleepers proving too weak for the loads. For the same reason the heavier type of construction put in to replace it in 1891, with sleepers 75 mm. (2.95 in.) deep and weighing 54 kgr. (119 lb.) gave no longer life on the more heavily worked lines and had to be replaced by the heaviest Baden design, with sleepers 100 mm. (3.94 in.) deep, weighing 70 kgr. (154 lb.).

To keep down the cost of steel sleepered permanent way it was originally the practice to lay the rails directly on the sleepers, making it necessary to bend or set them in two places in order to obtain the inward cant of the rails usual in Germany. This practice, which was retained in the case of the Baden forms of steel sleepered construction, proved unsatisfactory when the sleepers were too light, as bending resulted which led to spreading of the gauge, and the rails wore into the surface of the sleepers and weakened its upper wall, necessitating early renewal. These phenomena early led the Prusso-Hessian Administration to use bearing or sole plates, the wedge shaped form of which rendered any bending or setting of the sleeper unnecessary, while their larger load surface would reduce the wear and tear on the top face of the sleeper. Other German Administrations, especially the Würtemberg State Railways, also introduced such plates. On their upper face they had a hook shaped projection intended to hold the outer edge of the rail foot and were consequently known as hooked or shouldered sole plates. They were secured to the sleeper by a second hooked projection on their under face which engaged with the top wall of the sleeper outside the rail and, on the inside of the rail, by a claw bolt and clamp piece, which served at the same time to hold the rail fast.

The reason why in the German State Railways' B, or Baden, type and the Oldenburg type of permanent way, such sole plates have been given up, the rails once again resting direct on the sleepers, is because the sole plate construction has proved unsatisfactory under the constantly increasing loads to which it is subjected. The play, or tolerance, allowed between hook and rail foot and hook and sleeper holes, to compensate for any irregularity in forming the sleepers, led to a to and fro movement of the rail and plate under the influence of the traffic, leading to wear on the surfaces of the parts in contact. As it is not possible to tighten this form of construction in any way, recourse had to be had to filling the gaps that arose at the rail foot and in the sleeper holes by anything that was handy and convenient, in order to adjust the gauge or prevent further wear.

The securing of rails to steel sleepers — whether laid directly thereon or with the aid of sole plates — has hitherto necessitated a more or less extensive cold stamping of holes in the top wall of the sleeper. This has shown itself to be harmful to the life of the sleeper, as the hair cracks caused by the stamping spread under the hammering effect of passing loads and eventually led to fractures of the sleeper wall, which made the sleeper useless all the sooner the heavier the traffic. This circumstance has led to the holes being abandoned and to providing the sole plates in the latest type permanent way on the German State Railways with ribs at the side to receive the hook bolts.

Hitherto a special disadvantage of the wood sleeper has been declared to be its defective gauge holding quality, especially on curves, giving rise to misgivings concerning safe running. These criticisms of the earlier forms of permanent way construction have been entirely eliminated by the use of coach

screws instead of dog spikes, the employment of larger sole plates and hard wood sleepers, or soft wood sleepers in which the holes are provided with screw plugs, as well as the adoption of separate fastenings between the sole plate and sleeper and between sole plate and rail, as seen in the present German State Railways' type K track.

There is no doubt that the wood sleeper has the advantage over the steel one that its elasticity enables it to take the loads with some spring damping effect, giving smoother and quieter running. It likewise affords a steadier and firmer hold in the ballast, on account of its even bearing surface and greater depth, than is possible with the trough shaped steel sleeper, with its downward sloping walls penetrating into the ballast, necessitating constant packing to support it. It is precisely these properties which have induced the German State Railways to order that only wood shall be used in future on the most important express routes, in order to increase the comfort of travel in meeting the competition of road and air transport.

A further advantage of the wood sleeper is that it does not necessitate such a high quality ballast as the steel sleeper which, owing to its trough-like shape, requires much more extensive packing operations to obtain and retain a firm hold, which in turn induces a more rapid deterioration of the ballast material. The steel sleeper, moreover, requires more attention being given to the size of the stones used as ballast than does the wood sleeper, with which smaller sized pieces still permit of a good road bed being made, allowing of water draining freely through it for a considerable period. The author's experience is that with sifted gravel ballast, free from clayey particles, a wood sleepered permanent way can be established capable of meeting the requirements of high speed traffic. This is not the case with steel sleepers. The wood sleeper can thus be used everywhere where there is a lack of hard stone for ballast or the provision of suitable ballast is only possible at considerable cost, as for example in flat open country.

In addition, the wood sleeper is little affected by atmospheric conditions and can therefore be used where steel sleepers are out of the question. The latter are subject to rapid deterioration by rust in countries with a damp climate, in industrial districts where the air contains acid fumes, in tunnels, at level crossings, and in lines alongside platforms. On electric lines the insulation of the rails is easier to accomplish with wood than with steel sleepers, which has led to the general use of the former on track-circuited sections of line.

It must also be pointed out that derailments have, as a rule, much more serious consequences with steel than with wood sleepers. The wheel flanges of the derailed vehicles running over the steel sleepers, bend them, making the track unusable over a longer distance, so that vehicles behind the derailed one likewise leave the rails. The danger arising from this increases as the train speed while if a long length of track is damaged the renewal work is delayed and made more costly. Experience shows that with wood sleepers, as a rule, the wheel flanges can run over them without damage to the running qualities of the track.

Another disadvantage of the steel sleepered track is that it is much more liable to rail breakages in severe frost than one laid on wood sleepers, because the steel sleeper, less deeply embedded in the ballast, freezes fast, while the wood sleeper, which goes further down, retains the necessary elasticity and prevents excessive stresses arising in the rails. For example, in a long and severe winter experienced in the Breslau district, of the 76 rail breakages occurring on the main lines with the heavy 8, 15

and S 49 types of rail, 83 % were on steel sleepered tracks; of the total number of 92 rail breakages 86 % occurred on main line sections, 83.5 being on express routes. There were no special circumstances in this district to account for the unsatisfactory behaviour of the steel sleeper.

As regards the life of sleepers, the author does not consider the statements often repeated in the technical press, that steel sleepers last much longer than wood, to be generally justified. Such assertions rest, as a rule, on estimates of the case in which the individual attitude towards one or other type of sleeper plays a part. As an example of an overestimate we may take the case of the Prussian type 71 ribbed sleeper, the introduction of which in service was the object of an article by the Geheimer Kommerzienrat Dr.-Ing. Haarmann, entitled « Holzschwelle oder Eisenschwelle » (Wood or steel sleeper), in No. 36 (1908) of the journal « Stahl und Eisen », in which the author thought himself justified in prophesying a life of 30 years. Experience showed that the ribbed sleepers, which had a depth of 75 mm. (2.95 in.), weighed 62.39 kgr. (137.5 lb.) and in form and dimensions closely corresponded to the Prussian type 51 standard sleeper, only differing in the ribs on both sides of the top, did not prove at all satisfactory and were given up after a short period of service. They had too little cross rigidity, owing to their too shallow depth and wall thickness, while they deteriorated rapidly from rust, water deposited in the trough formed by the side ribs on the sleeper top being unable to flow away.

The long life of individual sleepers of one or the other kind, obtained in specially favourable circumstances, should not be taken as a criterion for the life of a particular type, which can only have any practical value when the average life of sleepers, based on statistical particulars concerning the date they were laid and withdrawn from service, for a large railway system, worked on uniform methods throughout, has been arrived at. Any comparison between the two kinds of sleeper also assumes that they are used with the same type of permanent way in all other respects. That the particulars given in the technical press concerning sleeper life differ so greatly is due to these points of view being insufficiently taken into consideration.

It must be said to the credit of the late Engineering and Traffic Inspector Biedermann that, on the basis of numerical examples taken from railway statistical returns, he devised a means of arriving at the average life of sleepering for a certain defined railway system, adapted to enable positive conclusions to be reached in this disputed question. He described his method in detail in issues Nos. 6, 7, 8 and 9 (1909) of the journal « Die Holzschwelle » (« The Wood Sleeper »), the organ of the Association for Promoting the Use of Wood Sleepered Track, and attention is directed to those articles. Biedermann investigated the conditions obtaining on the Prusso-Hessian State Railway system from 1848 to 1907 and ascertained that, for the types of sleeper used during that period, the average life of the steel type was in no way superior to that of the wood pattern. In addition, in No. 10 (1911), of the journal just cited, he gave an account of the simplified method adopted by the French engineer Couard, with which method he had become acquainted subsequently and, comparing it with his own, showed that the results of both methods largely agreed, as far as partial (annual) layings of sleepers, limited at each end, were concerned. He emphasised, however, that even with the Couard method, it was not possible to dispense with the static moments method given by himself in the case of different systems of permanent way over a more or less extended period.

In 1930, Dr.-Ing. Diehl, Reichsbahnrat, Karlsruhe, attempted, in a pamphlet published by the V.D.I., Berlin W. 7., and with the aid of Couard's method, to prove the long life of the steel sleepers used in the Baden type of track. He arrived at an exceptionally high average life, unattained up to the present, by a long way, by similar types of sleeper, for the 60-mm. and 75-mm. (2.36 and 2.95 in.) designs, weighing 42 and 54 kgr. (92.5 and 119 lb.) respectively. With regard to the heavy 100 mm. (3.94 in.) deep Baden sleeper, weighing 70 kgr. (154 lb.), definite results concerning its average life were not obtained, the inquiry only extending over a relatively restricted period of service and to part only of the sleepers laid down.

The surprising results of Diehl's investigations, and especially a comparison of them with figures published in the technical press on the life of wood sleepers at a time when insufficient impregnation and defective rail fastenings were hastening their decline in favour, led us to make a critical examination of the facts set forth in the pamphlet mentioned, the outcome of which was published in No. 12 (1931), of « Holzschwelle ». A reply from Dr. Diehl to our comments, with our own reply thereto, appeared in the following issue, No. 13.

While the light Baden type steel sleepers, 66 mm. and 75 mm. deep, may have actually enjoyed a longer life than other sleepers of similar design, there is no doubt that the reason can only lie in the exceptional circumstance that they were only kept in service on heavily worked running lines for 7 to 9 years and were then transferred to lines of lower class or sidings. If they had been kept for 18 to 20 years where they were first put down, as is generally the case with wood sleepers, the investigation into the question of average life would have given quite a different result. Although Roth and Schüler's system of rail fastenings marks an important step forward over the hooked sole plate method, the gauge adjusting filler pieces, which engage with the top face of the sleeper, give rise, under insufficient grip from the hooked plates, as a result of unavoidable play, to a vibratory movement in the rail, small indeed at first, but growing with increasing wear. In consequence, and also on account of the effect of the sleeper holes and the weakening of the upper wall through the rails being in direct contact with it, the lighter forms of Baden steel sleeper would have had a shorter life under continuous service on lines carrying heavy traffic.

The Baden form of rail fastening has also been applied to the German State Railways' type B permanent way, but although the fastenings were also made stronger in that case and the long form of rail joint was used, the type B track soon gave place to the K type, with steel sleepers. Although there is no doubt that the absence of holes in the sleepers promises a longer life in service with the last mentioned type of track, this is in like manner obtained with the K type track, laid on wood sleepers, owing to the separation of the fastenings for holding the sole plates to the sleepers from those for securing the rails to the plates. Longer life is also promoted by machine-boring the sleeper holes before impregnation is effected, incorrect and faulty boring, especially in comparison with the hand boring hitherto used, being avoided and the impregnating material reaching the interior of the holes and preventing rot from developing therein.

Experience alone can show what the average life of wood and steel sleepers will be in future with the new K type permanent way. It appears questionable whether the welding of the ribbed plates to the steel sleepers will prove satisfactory as regards sleeper life. As can be seen from the particulars given by Reichs-

bahnrat Marschner in No. 38 (1935) of « Der Bahn-Ingenieur » the welding on these plates cannot be regarded as a final solution of the matter. For this reason, experiments have been in progress for many years with the object of rolling these ribs and the recesses for the claw bolts integral with the sleeper, or pressing them out of its material. While with the wood sleeper a steady stage of development has now been attained, owing to its simple form and that of the rail fastenings used with it, the determination of the most suitable steel sleeper and rail fastenings is still in a state of transition, because difficulties are constantly being encountered which necessitate further modifications.

It now remains to deal with the behaviour of the two classes of sleeper in the course of regular maintenance, as this part of permanent way charges amounts to a considerable figure annually. Experience and data obtained show that the maintenance of track laid on wood sleepers is easier and cheaper than when steel sleepers are used. The wood sleeper, with its even bearing surface, is more easily packed, both when being laid and being maintained subsequently, than the trough shaped steel sleeper, with which the ballast has to be forced up to fill the trough space; the packing thus becomes more difficult as the depth and volume of this space increases. In this connection, special difficulty is met with in the case of the wide type steel sleeper, with which, on account of the greater width, considerably more ballast material has to be manipulated in order thoroughly to pack the trough shaped space. It follows from this that it is easier to inspect the packing in the case of the wood sleeper, while another consequence of the difficulty is that wood sleepered track retains its firmness longer than a steel sleepered one, the latter needing inspection at more frequent intervals. The broad type steel sleeper, sinking, as it does, more quickly into the ballast, proves correspondingly unsatisfactory from the point of view of a good and steady support for the rails. This is explainable also from the fact that the broad type wood sleeper, 2.60 m. (8 ft. 6 3/8 in.) long by 0.52 m. (20 1/2 in.) wide has a larger bearing surface than the Sw 2*a* type steel sleeper of the German State Railways' B type track, which is only 2.50 m. long (8 ft. 2 7/16 in.) and the Sw 8 sleeper of the K type track, which is only 0.452 m. (18 in.) at the foot. The unsatisfactory results obtained with these two types of sleeper led, in 1929, to the introduction of the broad Sw 11 type sleeper with the K type of track. This, of the same length as the wood sleeper, has a breadth at the foot of 0.50 m. (10 in.) and a bearing surface approximately equal to that of the wood sleeper.

That the intermediate 7*a* type sleeper used for the K type track fails to meet the requirements of lines carrying heavy traffic is proved by the fact that, according to the above-mentioned statements of Reichsbahnrat Maschner, a new cross section is being introduced experimentally, its surface breadth being 150 mm. (6 in.) and breadth at the base 290 mm. (11 7/16 in.). With this cross section the two limbs are formed like an S and have a broadened foot at the bottom. It is thought that this form will give a firmer bedding for the sleeper, the ballast resting on the foot helping to weight it. The experience so far gained with this sleeper makes it appear doubtful whether the development of the steel sleeper has yet been brought to a conclusion. The difficulty of obtaining a firm packing for the sleeper is also found with this form. It has been sought to overcome it, when laying track on the German State Railways, by using the so-called box formation method, in which, by means of suitably shaped boxes, or formers, the body of ballast intended to fill the

trough space of each sleeper is formed as a ridge on the previously rolled or tamped underlayer, the sleepers later being placed in position thereon. This process does indeed offer the great advantage that a newly laid track can, without disadvantage, be allowed to carry traffic at once but has nevertheless not proved entirely satisfactory, for no matter how carefully it is applied it is not possible to dispense with the packing tool when removing unavoidable defects later, or during revision maintenance work, especially when lifting dropped joints.

In issue No. 3 of « Gleistechnik und Fahrbahnbau », Karlsruhe, Reichsbahnrat Watteberg, of Berlin, describes the shovel packing process used for some 30 years in England and, since the war, in France, on the Northern and Eastern Railways. This process, which can only be used with wood sleepers, is said to offer considerable advantages, reducing maintenance costs, preserving the ballast in good condition and needing smaller gangs for the same work than ordinary beater packing. It is held to be especially advantageous at double sleepered rail joints or where sleepers are particularly close together, allowing of perfectly level sleepers being obtained and hence an excellent support for the joint. With ordinary packing, on the other hand, the sleepers may get set obliquely and the joints be forced down out of place if the joint sleepers are only packed on one side. Another advantage claimed for the shovel packing process is that, the work being easier, there is no encouragement to do it badly, while with the strenuous beater packing, or tamping process, there is a danger that the workmen may seek to lighten the work to the detriment of its quality. Besides this, the abolition of beater packing allows of using softer and cheaper kinds of stone for the ballast. That shovel packing is only possible with wood sleepered track is an advantage in favour of the latter.

To meet the disadvantage, frequently urged by the opponents of the wood sleeper, that it provides insufficient resistance to lateral displacement on curves, the German State Railways are providing so-called safety heads, or caps, to a certain proportion of the butt ends of the sleepers on the inner rails of curves. The official instructions for permanent way work limit this to curves of 500 m. (25 chains) radius and under, and preferably to those where long rails are in use.

The endeavour to standardise the work of permanent way staff and put it on a sound economic basis led the author, while engaged in the Breslau division, to have graphic work diagrams drawn up in each permanent way inspector's office, as a guide to the permanent way work on the through main lines, the operations to be carried out being entered on the diagrams with the estimated number of working days required according to the nature and extent of each operation. On completion of a particular job, the number of working days taken both for the complete work and for each kilometre of track, had to be noted down. Although difficulties were met with at the beginning, this was due to the fact that up to then the maintenance work was not undertaken on the broad lines of general overhaul but effected here and there, as occasion served. It was frequently noticed that the gang would be found working on the same stretch of line on several occasions at different times, often at short intervals. Such a method not only led to the steadiness of the road bed being disturbed, but to increased maintenance costs also, because the unproductive travelling to and from the site of necessity considerably reduced the effective work done by the men.

The particulars entered on the work diagrams formed an excellent means of judging of the suitability and necessity of the operations, of eliminating defects in the method of carrying out the work,

and of obtaining a comparison between the amount of labour needed with wood and steel sleepered track respectively. The author was able to ascertain, from information shown on such diagrams over a number of years, that with the Prussian 8d and 15 types of track with standard rail fastenings more working days were required for steel than for wood sleepered track, both for relaying and ordinary maintenance, to the extent of 22.3 % for the former and 15 % for the latter class of work. The saving obtained by using wood sleepers amounts to a considerable figure, spread over the extensive works of this kind on a large railway system. To this must be added the savings due to the smaller amount of ballast needed and its reduced rate of deterioration following the less intensive packing methods, while the quality of the ballast need not be so high.

The author is unable to express an opinion on how the circumstances are working out for the new German State Railways' permanent way, but believes himself justified, by his own experience, in thinking that the steel sleeper will necessitate a greater outlay in this case also, on account of the greater amount of packing work required with it than for wood sleepered track. The adoption of shovel packing for the latter would increase the difference still further.

3. **Conclusion.**

The author believes he has proved, by the above considerations, that the wood sleeper is best able to meet all the requirements, technical and economic, of permanent way construction and traffic working.

[625. 14 (01]

Primary stresses in railway tracks (1),

by W. E. GELSON, M. Inst. C. E.,

Research Officer, Central Standards Office for Railways, India.

PREFACE.

The author and Mr. E. A. Blackwood have made a large number of rail-stress and deflection measurements on various types of track with capacity loads at service speeds during the last two and a half years.

It is the purpose of this technical paper to put forward extensions of the « Continuous elastic support theory » which have been developed by the author to account for observed phenomena at speed in the solid rail and also to publish new applications of the theory to account for rail joint effect and to explain a method for calculating joint stresses and deflections. The mathematical results have been tested experimentally and the agreement is satisfactory.

* * *

This paper deals only with one part of the problem of track stresses namely with the stresses and reactions set up by vertical components of the wheel loads. Local strains in the rail head immediately under the wheel and those due to lateral and certain other oscillations are not here considered.

The continuous elastic support theory has been found to be useful for calculating rail bending moments, depressions and sleeper pressures under any combination of wheel loads which are stationary or moving slowly. This theory has been widely used for these purposes in Russia (2), America (3) and India (4) and the solutions for various conditions of static loading are obtained in « Applied Elasticity » by S. TIMOSHENKO, pages 133-143.

For a concentrated vertical load, P, on a rail of indefinite length in both directions, supported on a continuous elastic foundation which provides a vertical reaction uy per unit length, the depression of the rail at any point at a positive distance x from P is given by

$$y = \frac{P}{8\beta^3 EI} e^{-\beta x} (\cos \beta x + \sin \beta x) \quad . \quad (1)$$

where $$\beta = \sqrt[4]{\frac{u}{4\,EI}}$$

E = the modulus of elasticity of rail steel.

(1) This is Technical Paper No. 305, printed for the Railway Board of India, and reproduced here by courtesy of the Railway Board and the Author. Copies are obtainable from *The Manager of Publications*, Delhi (Price 8 annas or 9 d.). A catalogue of *Technical Papers* published by the Railway Board of India is obtainable from the Chief Controller, Central Standards Office for Railways, Railway Board, New Delhi.

(2) « Strength of rails », S. TIMOSHENKO, *Transactions Institute of Way and Communications* (1915), Petersburg, Russia.

(3) *Transactions American Society of Civil Engineers*, Vol. 82, page 1191 and Vol. 83, page 1409.

(4) Report of the Bridge Sub-Committee on Track Stresses, 1925, Technical Paper No. 245, Government of India Central Publication Branch, Calcutta.

I = moment of inertia of one rail.

u = vertical elastic modulus of the track, i. e., the number of force units per unit length of rail required to produce a uniform unit depression of the rail.

This is a solution of the equation :

$$\mathrm{EI}\frac{d^4y}{dx^4} + uy = 0 \quad \ldots \quad (2)$$

From (1) we get.

The bending moment $\mathrm{M} = - \mathrm{EI}\frac{d^2y}{dx^2}$

$$= -\frac{\mathrm{P}}{4\beta} e^{-\beta x} (\sin \beta x - \cos \beta x) \quad . \quad . \quad (3)$$

(1) and (3) are plotted in Fig. 1.

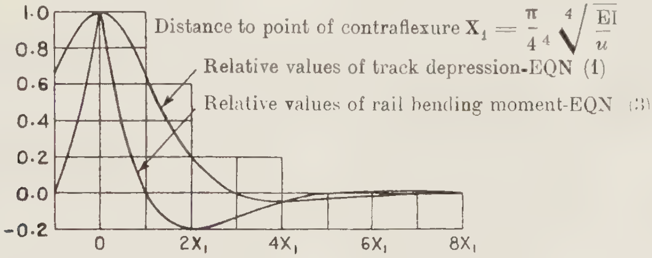


Fig. 1.

The maximum depression and maximum bending moment occur under P and are :

$$\Delta = (y)_{x=0} = \frac{\mathrm{P}}{8\beta^3\mathrm{EI}} = \frac{\mathrm{P}\beta}{2u}$$

and

$$\mathrm{M} = (\mathrm{M})_{x=0} = \frac{\mathrm{P}}{4\beta}$$

The curves for y and M, Fig. 1, are also influence lines for a moving load, P, and therefore the depression and bending moment for combinations of wheel loads can be determined by superposing curves from each wheel, giving each its proper amplitude and phase relation. The above theory has been accepted as a basis of rail stress calculations for Indian Railways where it has been in general use since 1925. Recent tests on Indian Railways have confirmed that the elastic theory outlined above usually fits actual conditions in the track very well. Cases, however, have been noticed, particularly in station yards, where the depressions and moments have been less than those predicted by the above theory, and the discrepancies have been traced to an arching effect by which the sleepers have become so well consolidated in the track formation, that their reactions have an horizontal component in a direction opposite to that of the elastic strain in the rail foot, thus affording considerable relief of rail stress. Cases of this kind are, however, comparatively rare, and equation (2) is retained in favour of

$$\mathrm{EI}\frac{d^4y}{dx^4} + \lambda\frac{d^2y}{dx^2} + uy = 0. \quad . \quad . \quad (4)$$

where λ is a constant multiplied by the curvature of the rail, and is determined by experiment for cases where the arching effect is noticeable.

Defective sleepers, or non-uniformity of under ballast may cause considerable rail stress and depression over and above the values given by (1) and (3).

With the track maintenance usual on Indian main lines such additional effects have not been found to be large.

Calculation of speed effect. — It is of interest to investigate the effect of speed of the moving load on the depression

and bending moment curves. For this purpose a factor m is introduced for the effective deflecting mass of the track and a factor N for damping forces. For a continuous rail of infinite length, supported on a uniformly elastic formation traversed by a concentrated load P at velocity v, we have :

$$\mathrm{EI}\frac{d^4y}{dx^4} + m\frac{d^2y}{dt^2} + \mathrm{N}\frac{dy}{dt} + uy = \frac{2\mathrm{P}}{l}\left[\sin\frac{\pi x}{l}\sin\frac{\pi vt}{l} + \sin\frac{2\pi x}{l}\sin\frac{2\pi vt}{l} + \sin\frac{3\pi x}{l}\sin\frac{3\pi vt}{l} + \&c.\right] \quad (5)^*$$

where $l \geq \frac{4\pi}{\beta}$

The damping is taken to be of the fluid friction type, proportional to velocity.

The depression of the rail after free oscillations have been damped out will be given by the particular integral of (5), i. e.,

$$y = \frac{\mathrm{P}}{l}\left[\frac{\left\{\mathrm{EI}\left(\frac{\pi}{l}\right)^4 - (2\pi n)^2 m + u\right\}\cos\left(\frac{\pi x}{l} - 2\pi nt\right) - 2\pi n\,\mathrm{N}\sin\left(\frac{\pi x}{l} - 2\pi nt\right)}{\left\{\mathrm{EI}\left(\frac{\pi}{l}\right)^4 - 4\pi^2n^2m + u\right\}^2 + 4\pi^2n^2\mathrm{N}^2}\right.$$

$$- \frac{\left\{\mathrm{EI}\left(\frac{\pi}{l}\right)^4 - 4\pi^2n^2m + u\right\}\cos\left(\frac{\pi x}{l} + 2\pi nt\right) - 2\pi n\,\mathrm{N}\sin\left(\frac{\pi x}{l} + 2\pi nt\right)}{\left\{\mathrm{EI}\left(\frac{\pi}{l}\right)^4 - 4\pi^2n^2m + u\right\}^2 + 4\pi^2n^2\mathrm{N}^2}$$

$$+ \frac{\left\{\mathrm{EI}\left(\frac{2\pi}{l}\right)^4 - (4\pi n)^2 m + u\right\}\cos\left(\frac{2\pi x}{l} - 4\pi nt\right) - 4\pi n\,\mathrm{N}\sin\left(\frac{2\pi x}{l} - 4\pi nt\right)}{\left\{\mathrm{EI}\left(\frac{2\pi}{l}\right)^4 - (4\pi n)^2 m + u\right\}^2 + (4\pi n)^2\mathrm{N}^2}$$

$$\left. + \&c \right] \quad (6)$$

where

$$n = \frac{v}{2l}$$

It is an unfortunate circumstance that the evaluation of equation (6) to a sufficient degree of accuracy for comparative purposes is very laborious, owing to the slow convergence of the series. This however has been done for the representative track conditions stated below.

Elastic lines are plotted in Fig. 2 for an isolated wheel load of 20 000 lb. associated with the following track conditions :

$\mathrm{E} = 30 \times 10^6$ lb. per sq. inch.

$\mathrm{I} = 38.45$ inches^4 (flat-flooted rail weighing 90 lb. per yard).

$u = 1\,700$ lb. per sq. inch.

$l = 504$ inches.

$v = 1\,056$ inches per second (60 m.p.h.).

The lines are plotted for three combinations of m and N as indicated on Fig. 2 from which it will be seen that the effect of N is to make the curve unsymmetrical about the y axis. The effect of m is to increase the depressions and to squeeze

(*) The idea of expressing the loading of a beam in the form of an harmonic series has been developed by Professor C. E. INGLIS, vide « A mathematical treatise on vibrations in Railway Bridges ». Cambridge 1934.

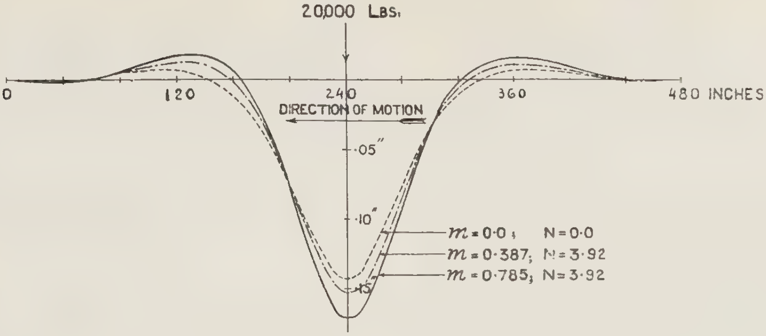


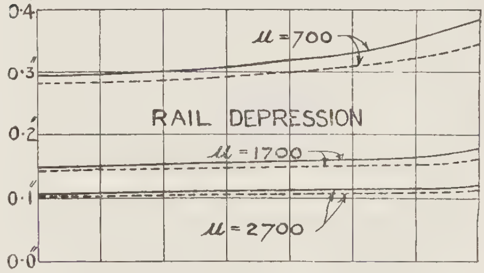
Fig. 2.

in both limbs of the curve towards the y axis.

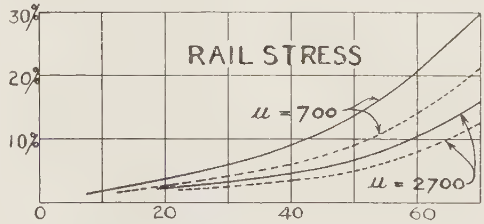
Approximate determination of m is possible by comparing the depression time diagrams of wheel loads moving at high speeds, with those obtained at very slow speeds. It is not certain that m is entirely independent of load and speed.

The amount of damping effect can be estimated from deflection time diagrams for a point on the rail, as the load slowly advances, and passes over a small obstacle placed on the top of the rail to set up free oscillations. These oscillations in the case of ballasted track are usually heavily damped. $N = 3.92$ is a suitable value for the type and weight of track assumed in the calculations upon which curves on Fig. 2 are based.

Bending moments. — The curve of rail bending moment derived from (6) is given by



Full lines denote total ranges.
Dotted lines denote peak values.



Speed, miles per hour.

Fig. 3.

$$M = -\,EI\,\frac{d^2y}{dx^2}$$

$$= -\,EI\,\frac{\pi^2 P}{l^3}\left[\frac{-A_1\cos\left(\frac{\pi x}{l}-2\pi nt\right)+2\pi n N\sin\left(\frac{\pi x}{l}-2\pi nt\right)+A_1\cos\left(\frac{\pi x}{l}+2\pi nt\right)+}{A_1^2+N^2(2\pi n)^2}\right.$$

$$+\frac{2\pi n\,N\sin\left(\frac{\pi x}{l}+2\pi nt\right)}{A_1^2+N^2(2\pi n)^2}+\frac{2^2\left\{-A_2\cos\left(\frac{2\pi x}{l}-4\pi nt\right)+4\pi n N\sin\left(\frac{2\pi x}{l}-4\pi nt\right)\right\}+}{A_2^2+N^2(4\pi n)^2}$$

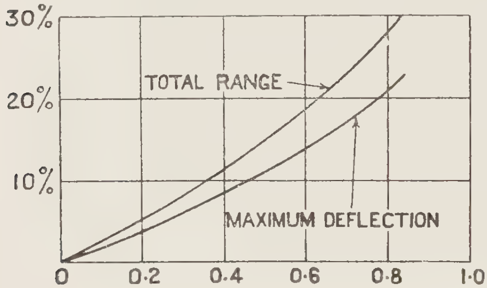
$$\left.+\frac{2^2\left\{A_2\cos\left(\frac{2\pi x}{l}+4\pi nt\right)+4\pi n N\sin\left(\frac{2\pi x}{l}+4\pi nt\right)\right\}}{A_2^2+N^2(4\pi n)^2}+\&c.\right] \quad \ldots\ldots \quad (7)$$

where

$$A_1 = EI\left(\frac{\pi}{l}\right)^4 - m\frac{\pi^2 v^2}{l^2} + u,$$

$$A_n = EI\left(\frac{n\pi}{l}\right)^4 - m\left(\frac{n\pi v}{l}\right)^2 + u.$$

Curves Figs. 3 which have been derived from equations (6) and (7) show the variation in depression with speed and the percentage increment in stress with speed for $m = 0.387$ (*) and $N = 3.92$, and $I = 38.45$. It will be noted that high values of u have the beneficial effect of reducing the speed increment. Fig. 4 shows the percentage increment in de-



Value of m.

Fig. 4.

pression to a base of m for $u = 1\,700$, $N = 3.92$ for a constant speed of 60 m.p.h. The importance of selecting a value for m which fits experimental observations in clear from Fig. 4.

After the allowance for speed effect has been made, the effect of low points in the track has to be considered.

depression under the moving wheel load would be constant. Such conditions could by very approximately attained if :

(*a*) the sleeper spacing were uniform throughout and the moment of inertia of a pair of fish-plates equalled that of the rail, or

(*b*) if the sleeper spacing were uniform throughout and the effective length of the fish-plates were negligibly small.

Normal types of fish-plates are rarely designed with a moment of inertia per pair greatly exceeding 30 per cent of that for the solid rail, and where specially deep and angle type plates are used, there is complexity in the stress distribution and often overstress under working conditions. Reduction in the effective length of fish-plates (i. e., by making them very stiff), and curtailment of the length of the fishing surfaces, sometimes results in very high web stresses in the rail which have caused the rail head to be torn from the web.

In practice, a compromise has to be made, and the joint and shoulder sleepers are commonly brought to a closer spacing, and the joint sleepers are sometimes given a greater effective bearing area. The effectiveness of a given joint design can be readily tested approximately by the principle of least work.

M_0 is the bending moment in the fish-

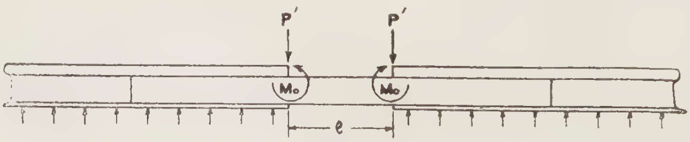


Fig. 5.

Design of rail joints. — The influence line for the depression at a perfect rail joint is given by equation (1) i. e., the plate of effective length, l. See schematic diagram Fig. 5 (not to scale). The load 2W is assumed to have reached the joint. The joint sleepers are assumed to be arranged so that there is additional

(*) Lb. mass per inch.

bearing area 2ε expressed as a fraction of the effective area of one intermediate sleeper in the neighbourhood of the joint, sufficient to reduce the deflection here to that of the solid rail under the load.

If ρ is the stiffness of an intermediate sleeper and Δ_1 is the depression of the track under 2W at the joint

$$P = 2W$$

$$\text{also} \quad \acute{P} = W - \rho\Delta_1\varepsilon$$

If Ip = moment of inertia of a pair of fish-plates, the strain energy in the fish-plates of effective length l is :

$$\frac{M_0{}^2 l}{2EIp}$$

and in the rails

$$2\int_0^{\frac{2\pi}{\beta}} \frac{M^2}{2EI}\,dx =$$

$$= \int_0^{\frac{2\pi}{\beta}} \frac{e^{-2\beta x}}{\beta^2 EI}\Big[\sin^2\beta x(\acute{P}^2 - 2\beta\acute{P}M_0) +$$

$$+ B^2M_0{}^2 + \sin 2\beta x\,(M_0{}^2\beta^2 - \beta\acute{P}M_0)\Big]\,dx =$$

$$= \frac{1}{\beta^2 EI}\left[\frac{3\beta M_0{}^2}{4} + \frac{\acute{P}^2}{8\beta} - \frac{\acute{P}M_0}{2}\right]$$

and on the ballast and formation

$$u\int_0^{\frac{2\pi}{\beta}} y^2\,dx =$$

$$= u\int_0^{\frac{2\pi}{\beta}} \frac{1}{4\beta^6E^2I^2}\Big[\cos^2\beta x l^{-2\beta x}(\acute{P}^2 - 2\acute{P}\beta M_0)$$

$$+ \beta^2M_0{}^2 l^{-2\beta x} - l^{-2\beta x}\sin 2\beta x(B^2M_0{}^2 -$$

$$- \acute{P}\beta M_0)\Big]\,dx = \frac{1}{\beta^2 EI}\left[\frac{M_0{}^2\beta}{4} + \frac{3\acute{P}^2}{8\beta} - \frac{\acute{P}M_0}{2}\right].$$

The total strain energy

$$U = \frac{1}{\beta^2 EI}\left[M_0{}^2\beta + \frac{\acute{P}^2}{2\beta} - \acute{P}M_0\right] + \frac{M_0{}^2 l}{2EI\rho}$$

$$\frac{du}{dM_0} = \frac{1}{\beta EI}\left[2\beta M_0 - \acute{P}\right] + \frac{lM_0}{EI\rho} = 0$$

$$M_0 = \frac{\acute{P}}{\beta}\left[\frac{I\rho}{2I\rho + I\beta l}\right]$$

There is in addition work absorbed in friction principally due to sliding at the fishing planes but in well maintained track, this is sufficiently small to be neglected here.

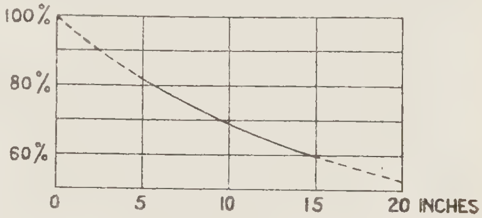


Fig. 6.

The relation between M_0 and l as a percentage of the solid rail bending moment is shown by the graph Fig. 6 for the following example :

Rail 90 lb., flat footed, I = 38.45 in.[4]

β = 0.025 and I_ρ = 10.8 in.[4]

The above method of determining fish-plate bending moment applies only when the additional sleepering is close to the centre of the joint as in the case of the Indian Railway Standard Duplex joint sleepers. In other cases if $\rho\Delta_1\varepsilon$ acts at a distance a from the centre of the joint, M_0 is replaced by $(M_0 - \rho\Delta_1\varepsilon a)$ in the above calculation.

To find the trajectory of a moving axle load when passing over a rail joint.

Referring to Fig. 7

Let 2R = total vertical reaction from extra joint sleepering when P is at the joint J.

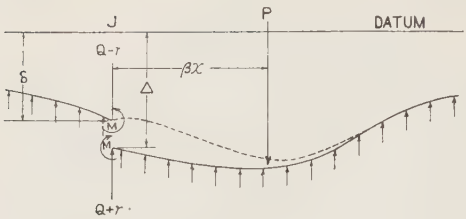


Fig. 7.

$2r$ = reaction at joint due to extra joint sleepering when P is distant βx from the joint J.

M_0 = bending moment in fish-plate when P is at the joint J.

δ_0 = depression at the joint when P is at the joint J.

Q = shear in fish-plate when load is distant βx from joint J.

M = bending moment in fish-plate when load is distant βx from joint J.

δ = depression at J when load is distant βx from J.

δ_1 = depression at J, due to P, supposing the rail to be unbroken there, and the sleeper spacing to be normal.

δ_2 = depression additional to δ_1 on account of a complete break in the rail at J.

$$\Delta = \delta_1 + \delta_2$$

$$\delta = \frac{e^{-\beta x}}{2\beta^3 EI}\left[\left(\frac{P}{2} - R\right)\cos\beta x - M_0\beta(\cos\beta x - \sin\beta x)\right] \quad (8^*)$$

$$\delta_1 = \frac{P e^{-\beta x}}{8\beta^3 EI}(\cos\beta x + \sin\beta x) \quad (9)$$

$$\delta_2 = \frac{P e^{-\beta x}}{8\beta^3 EI}[3\cos\beta x - \sin\beta x] \quad (10)$$

(*) Maxwell's rule for reciprocal deflections. Reference may be made to « Applied Elasticity » by S. TIMOSHENKO, page 140.

$$\Delta = \frac{P}{2\beta^3 EI} e^{-\beta x}\cos\beta x \quad (11)$$

$$\delta = \frac{1}{2\beta^3 EI}(Q - r - \beta M) \quad (a)$$

$$\Delta - \delta = \frac{1}{2\beta^3 EI}(Q + r + \beta M) \quad (b)$$

$$Q = \beta^3 EI\,\Delta \quad (c)$$

$$M = (\Delta - 2\delta)\,\beta^2 EI - \frac{r}{\beta} \quad (d)$$

$$r = \frac{2\beta^3 EIR\delta}{\frac{P}{2} - R - M_0\beta} \quad (e)$$

The required deflection at P is the deflection at P assuming a complete break in the rail at J and with no extra sleepering at J minus the deflection at P due to M and Q + r at J.

The trajectories for a 20 000 lb. wheel load moving slowly have been plotted in Fig. 8 for the following six track conditions.

Rail. — 90 lb. flat-footed, I = 38 . 45 inches.

Fish-plates. I per pair = 10 . 8 inches[1].

Curve No.	Elastic constant.	Solid rail depression.	Depression at joint.
1	1 300	0.1 775"	0.1 598"
2	1 300	0.1 775"	0.1 775"
3	1 820	0.1 385"	0.1 246"
4	1 820	0.1 385"	0.1 385"
5	2 300	0.1 160"	0.1 043"
6	2 300	0.1 160"	0.1 160"

Dynamic effects due to rail joints. — Rail joints set up vertical oscillations in the track and in the moving sprung and unsprung masses. The remaining paragraphs of this paper deal with these vertical oscillations of the track.

To find the equivalent length of track

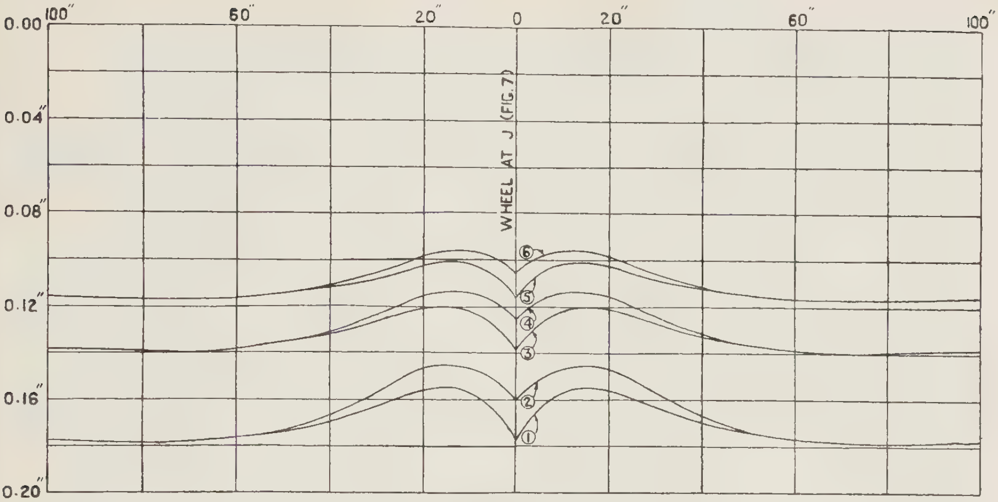


Fig. 8.

of mass m per unit length which must be added to the unsprung weight of one axle, it is assumed that the elastic curve of the rail during oscillation is of the same form as for a concentrated static load.

If y represents the vertical velocity of the wheel, then the kinetic energy of the track of mass m per unit length will be :

$$2\int_{0}^{\frac{2\pi}{\beta}} \dot{y}^2 \frac{m}{2} e^{-2\beta x} (\cos \beta x + \sin \beta x)^2 \, dx$$

$$= \frac{3}{4}\frac{m}{\beta}\dot{y}^2 \text{ very approximately.}$$

If $\beta = 0.025$, then the mass of a length of track equal to 30 inches has to be added to the unsprung portion of the wheel load.

Taking another case, namely when the wheel load is close to a rail joint. The sleepers are assumed to be uniformly spaced, and the fish-plates are capable of transmitting the full shear and negligible bending moment. The kinetic energy of the track is then :

$$\int_{0}^{\frac{2\pi}{\beta}} \dot{y}^2 \frac{m}{2} e^{-2\beta x} \cos^2 \beta x \, dx =$$

$$= \frac{3}{8}\frac{m}{\beta}\dot{y}^2 \text{ very approximately.}$$

If $\beta = 0.025$, then the mass of a length of track at the joint equal to 15 inches has to be added to the unsprung portion of the wheel load. *The above corrections are of little importance for normal values of m.*

To calculate the vibration due to a wheel load passing over an irregularity such as one of the trajectories in Fig. 8.

Let :

W_1 = total unsprung portion of the wheel load including the effective mass of the track.

W_2 = Total sprung mass for one wheel load.

K_1 = Vertical stiffness constant for the track.

K_2 = Vertical stiffness constant for the vehicle spring.

y_1 = Displacement of W_1 from its equilibrium position.

y_2 = Displacement of W_2 from its equilibrium position.

$2n$ = Damping co-efficient for spring K_1.

We have

$$\frac{W_1}{g}\frac{d^2y_1}{dt^2} + 2n\frac{W_1}{g}\frac{dy_1}{dt} + \overline{K_1 + K_2}\,y_1 -$$

$$- K_2 y_2 = \frac{W_1}{g} f''(t)$$

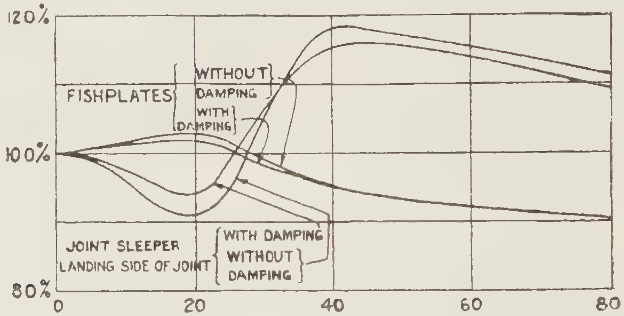
$$\frac{W_2}{g}\frac{d^2y_2}{dt^2} + K_2 y_2 - K_2 y_1 \cdot = 0$$

where f'' (t) in the forced acceleration of W_1 due to the irregularity.

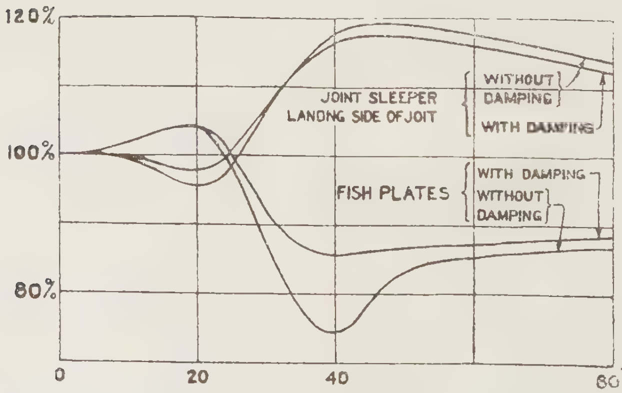
Two important cases are considered, namely :

(*a*) when the spring K_2 is frictionless as in springs of the helical type and when K_2 is quite small compared with K_1.

(*b*) when the spring K_2 is of the laminated type in which case the amplitude of oscillations due to irregularities of similar magnitude to those shown in Fig. 8 are insufficient to break down the spring friction. K_2 will then be the higher spring con-



Speed, miles per hour.
Case *(a)*, Figs. 9.



Speed, miles per hour.
Case *(b)*, Figs. 9.

stant for the laminated spring, modified on account of the combined flexibility of spring rigging, solebars, etc. (1).

Cases (*a*) and (*b*) have been worked out for the following conditions.

$u = 1\,300$ and trajectory as for curve 1, Fig. 8.

$W_1 = 4\,500$ lb.

$W_2 = 15\,500$ lb.

$K_1 = 112\,800$ lb. per inch.

$K_2 = 42\,000$ lb. per inch.

For zero damping and also for moderate damping (common ratio of residual oscillations = 0.6).

The results in the form of percentage variation in fish-plate stress and landing joint sleeper pressure to a speed base for case (*a*) and case (*b*) are given in Fig. 9. The theoretical results are in general agreement with experiments on fish-plate stresses and shoulder sleeper deflections for well packed joints.

These dynamic effects can be greatly reduced by deforming the rail near its ends into opposite curvature to the trajectories shown in Fig. 8. Owing however, to the varying axle loads usually running on particular sections, such ideal conditions can only be realized, partially. A proposal has been made to bend up the rail about 0.03" from a point about 15 inches from its end, and to introduce an initial permanent set in the fish-plates to suit the upward cant of the rail end (2).

Acknowledgement. — The author received valuable assistance with the computations and curve plotting from Mr. S. S. VARMA, Assoc. M. Inst. C. E., A. M. I., Struct. E., of the Engineering Department in the Central Standards Office.

(1) Reference may be made to the author's paper No. 5126, pages 295-304, Journal Inst. C. E., No. 5, March 1938, in which particulars are given of friction in laminated springs.

(2) British patent application No. 9378/38 of 26th March, 1938.

[621. 132.3 (.73)]

4-6-4 type streamline passenger locomotives with welded fireboxes,

Chicago, Milwaukee, St. Paul and Pacific Railroad.

(*Railway Mechanical Engineer.*)

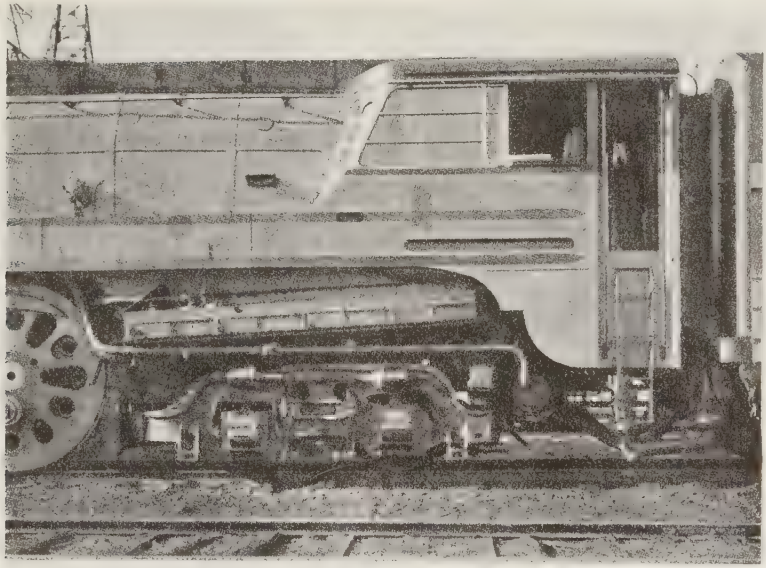
In August 1938, the American Locomotive Company delivered, from its Schenectady, N. Y., plant, six 4-6-4 type heavy passenger locomotives for service on the Chicago, Milwaukee, St. Paul and Pacific. While the new locomotives follow the general appearance of the original Hiawatha they are not solely for service on that train, but will be used on the Olympian and Pioneer Limited trains between Chicago and Minneapolis, a distance of 418 miles, and west of Minneapolis on the Olympian, to Harlowton, Montana, a distance of 914 miles. In the development of this « speedlined » design, Otto Kuhler, consulting engineer of design, collaborated with the railroad company and the builders.

These locomotives develop a tractive force of 50 300 lb. with a boiler pressure of 300 lb. and 84-in. driving wheels. The tenders carry 20 000 gallons of water and 25 tons of fuel.

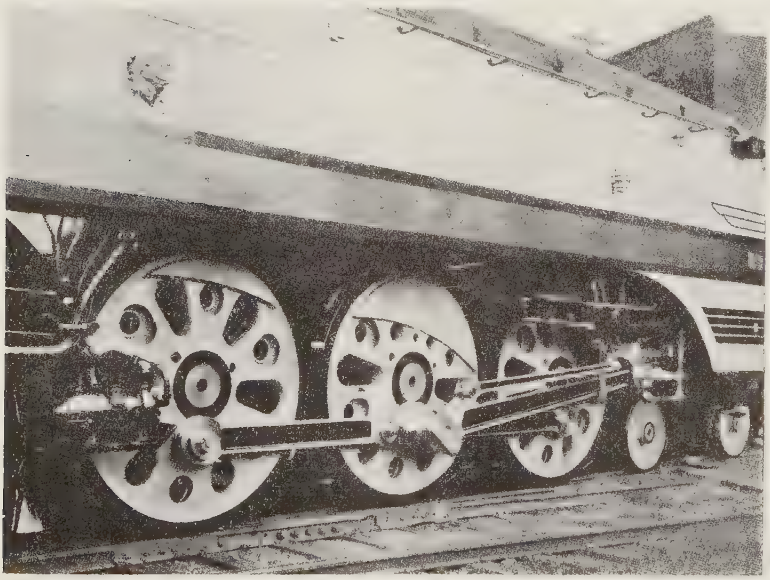
Machinery details.

The foundation of these locomotives is a General Steel Castings Corporation's engine bed in which the cylinders, back cylinder heads, center plates, air reservoirs, link support, guide-yoke brackets, expansion-shoe pads, air-pump brackets and driver-brake fulcrums are cast as an integral part of the bed. The boiler is supported at the front and back of the firebox on expansion shoes, at the cylinders and by a waist sheet between the first and second pair of drivers.

The engine trucks are the General Steel Castings four-wheel type with 36-in. Davis cast-steel wheels, A. S. F. clasp brakes and Timken roller bearings. The driving wheels have Boxpok centers, 84-in. tires and Timken roller bearings. The journal diameter is 13 1/2 in. at the main wheel and 12 1/2 in. at the front and back. The Alco lateral-motion de-



The vestibule cab is of distinctive design and has a window arrangement which provides unusual visibility.



The design of the streamline shrouding is such that the running gear is completely exposed.

vice is installed on the front pair of drivers.

The trailing truck is the Delta four-wheel type with centering device, furnished by the General Steel Castings Corporation with 38-in. Davis wheels at the front and 44-in. steel-tired wheels at the rear of the truck. The trailer wheels are equipped with A. S. F. roller-bearing units and clasp brakes.

The cylinders are 23 1/2 in. bore by 30 in. stroke. Walschaerts valve gear controlled by an Alco type H reverse gear actuates the 12-in. piston valves. The cylinder and valve chamber bushings are of Hunt-Spiller gun iron. The Z-type pistons are of rolled steel and both pistons and valves are fitted with Hunt-Spiller Duplex packing rings. Those on the pistons are the locked-lip type which require no bull ring and the valve rings are sectional bronze and iron.

The piston rod is of medium carbon steel, normalized and tempered, and is 5 in. in diameter. The crosshead and guides are of the multiple-bearing type. The main and side rods are of low-carbon nickel steel normalized, quenched and tempered. Floating bronze bushings are used at all pins with Hunt-Spiller fixed bushings in the rods. The crank pins are medium carbon steel and the main pin is hollow-bored.

The revolving weights at all wheels are cross-counterbalanced. The total weight of the reciprocating parts on each side is 1 681 lb.; the overbalance is 196 lb. on each wheel. The dynamic augment at 84 m. p. h. is 9 400 lb. in each wheel.

The boilers.

The boilers on these locomotives are built in three courses, the middle or dome course being conical in form. The inside diameter of the first course is 82 1/2 in. and the outside diameter of the third course is 94 in. The thickness of the plate in the first course is 7/8 in. and 31/32-in. plates are used in the second and third courses. The three barrel courses, welt strips and dome liner are silico-manganese steel having a maximum tensile strength of 82 000 lb. The front tube sheet is 3/4 in. thick and the back tube sheet is 5/8 in. thick. The firebox is 96 3/16 in. wide by 144 15/32 in. long. The height from the bottom of the mud ring to the top of the crown sheet is 73 1/2 in. at the rear and 88 13/16 in. at the front. The water space is 5 in. at the sides and back and 6 in. at the front of the firebox. The length of the combustion chamber is 44 1/2 in. The roof and sides of the firebox are of silico-manganese steel similar to that used in the barrel course.

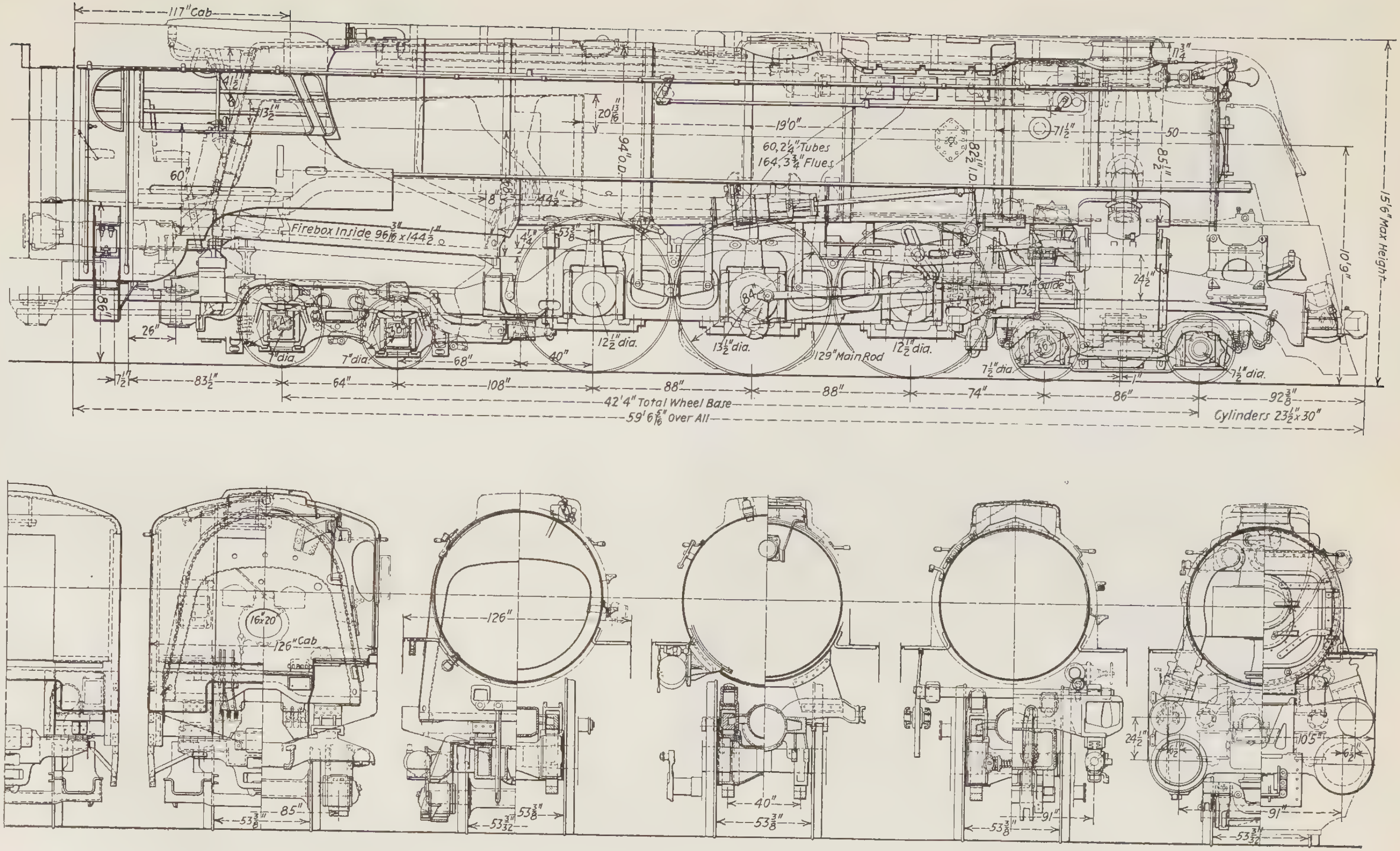
The roof sheet is 13/16 in. thick while the outside side sheets are 9/16 in. thick. The inside firebox sides and crown consist of three 13/32 in. sheets welded together. Two Thermic syphons are located in the firebox, and a third one on the center line of the boiler is in the combustion chamber. In addition to the two syphons in the firebox, there are two 3 1/2-in. arch tubes which, together with the syphons, support the American brick arch.

The boilers are fitted with sixty 2 1/4-in. tubes and one-hundred-sixty-four 3 3/4-in. flues. The length over the tube sheets is 19 ft.

The firebox is arranged for bituminous coal using Firebar grates. The grate area is 96.5 sq. ft. Coal is fed by means of a Standard modified type B stoker. The ash pans are of welded steel plate with cast-steel hoppers.

The fireboxes of these locomotives are completely welded. The firedoor flange, inside door sheet, inside throat sheet and back tube sheet, as well as the longitudinal seams which join the crown and inside firebox side sheets are welded butt joints.

Alco flexible stays have been used extensively. Flexible expansion stays of the WZ type are used in the first six rows across the front of the combustion

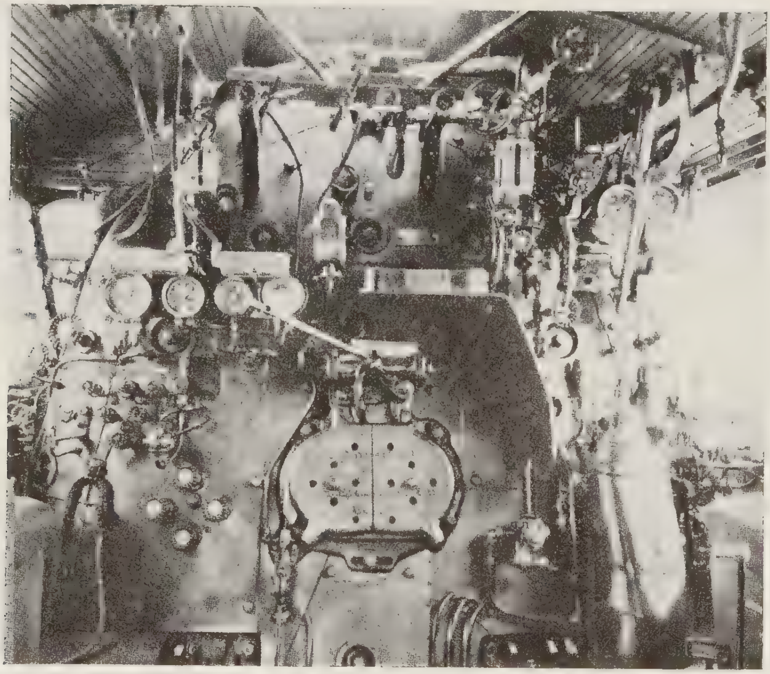


Elevation and cross-section of the Milwaukee 4-6-4 type passenger locomotive.

General dimensions, weights and proportions of the C. M St. P. & P. 4-6-4 type locomotives.

Railroad	C.M.St.P. & P.
Builder	American Locomotive Co.
Type of locomotive	4-6-4
Road class	F-7
Road numbers	100-105
Date built	1938
Service	Passenger
Dimensions :	
Height to top of stack, ft.-in.	15—3
Height to center of boiler, ft.-in.	15—6
Width overall, ft.-in.	10—6 1/2
Cylinder centers, in.	91
Weights in working order, lb.:	
On drivers	216 000
On front truck	82 500
On trailing truck :	
Front	53 000
Back	63 500
Total engine	415 000
Tender	375 000
Wheel bases, ft.-in. :	
Driving	14—8
Rigid	14—8
Engine, total	42—4
Engine and tender, total	89—10
Wheels, diameter, outside tires, in. :	
Driving	84
Front truck	36
Trailing truck :	
Front	38
Back	44
Engine :	
Cylinders, number, diameter and stroke, in.	2-23 1/2 × 30
Valve gear, type	Walschaerts
Valves, piston type, size, in.	12
Maximum travel, in.	7 1/2
Steam lap, in.	1 5/16
Exhaust clearance, in.	1/4
Lead, in.	5/16
Cut-off in full gear, per cent.	84
Boiler :	
Type	Straight top
Steam pressure, lb. per sq. in.	300
Diameter, first ring, inside, in.	82 1/2
Diameter, largest, outside, in.	94
Firebox length, in.	144 1/2
Firebox width, in.	96 3/16
Height mud ring to crown sheet, back, in.	73 1/2
Height mud ring to crown sheet, front, in.	88 13/16
Combustion chamber length, in.	44 1/2

Arch tubes, number and diameter, in.	2 3 1/2
Thermic syphons, number	3
Tubes, number and diameter, in.	60—2 1/4
Flues, number and diameter, in.	164—3 3/4
Length over tube sheets, ft.-in.	19—0
Fuel	Bituminous
Grate area, sq. ft.	96.5
Heating surfaces, sq ft :	
Firebox and comb. chamber	348
Arch tubes	19
Thermic syphons	91
Firebox, total	458
Tubes and flues	3 708
Evaporative, total	4 166
Superheating	1 695
Combined evap. and superheat.	5 861
Tender :	
Type	Rectangular
Water capaiity, gal.	20 000
Fuel capacity, tons	25
Trucks	6-wheel
Rated tractive force, engine, lb.	50 300
Weight proportions :	
Weight on drivers ÷ weight engine, per cent.	52.1
Weight on drivers ÷ tractive force	4.29
Weight of engine ÷ evaporation	99.6
Weight of engine ÷ comb. heating surface	70.8
Firebox heat. surface, per cent comb. heating surface	78.1
Tube-flue heat. surface, per cent comb., heating surface	63.3
Superheat surface, per cent comb. heating surface	28.9
Firebox heating surface ÷ grate area	4.75
Tube-flue heating surface ÷ grate area	38.4
Superheat. surface ÷ grate area	17.6
Comb. heat. surface ÷ grate area	60.8
Evaporation ÷ grate area	43.2
Tractive force ÷ grate area	521.0
Tractive force ÷ evaporation	12.1
Tractive force ÷ comb. heating surface	8.58
Tractive force × diameter drivers ÷ comb. heating surface	721.0



The cab window arrangement of these locomotives provides a well lighted interior.

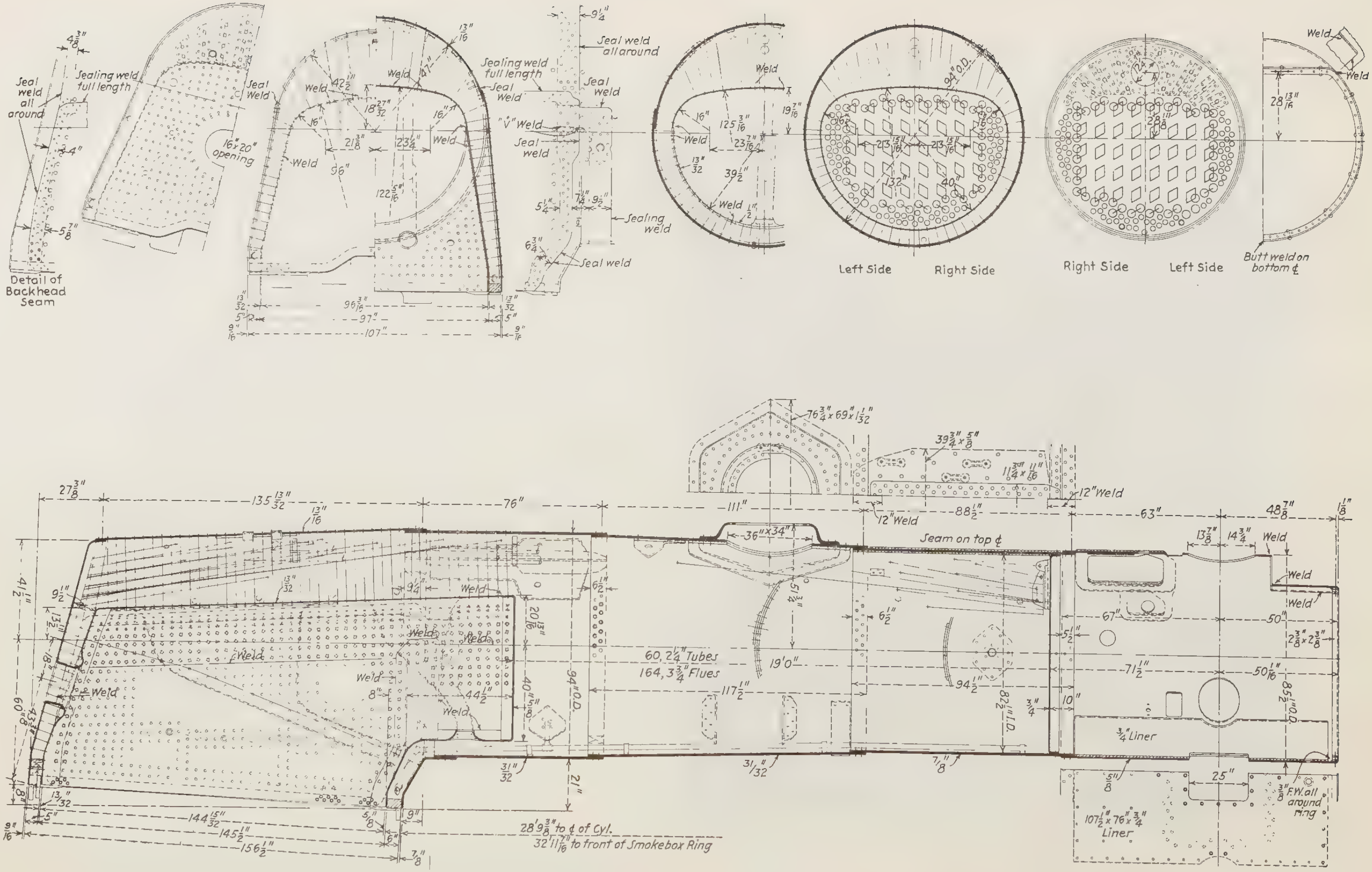
chamber. Two rows of flexible radials of the WY type are used at the edge of the crown sheet. WZ type sleeves and caps are used for the flexible water space stays in the combustion chamber as well as a complete installation in the throat sheet. WZ type flexible water space stays are used in the breaking zones of the side and back head. There are four 2-in. combustion flues on each side of the firebox.

The boilers are equipped with the Barco type F3a low-water alarm, Wilson sludge remover together with Wilson blow-off cocks and muffler. Franklin butterfly type firedoors, Superior flue blowers and T-Z smoke consumers constitute part of the equipment.

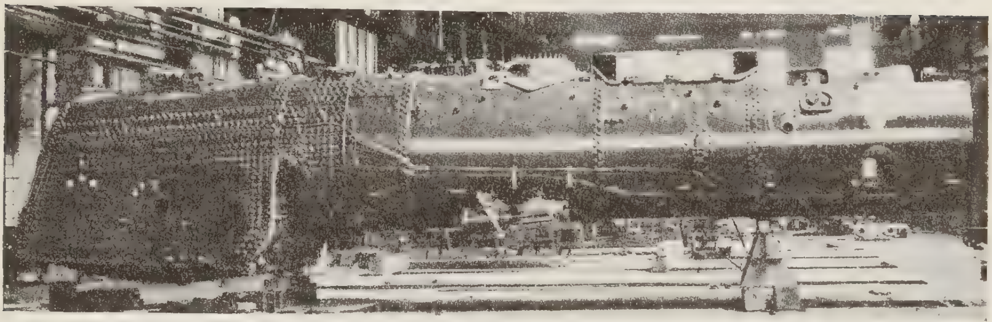
Saturated steam passes through a Tangential steam dryer in the dome, through a 10-in. diameter steel dry pipe to an American multiple throttle built into the header of the type E superheater.

Cab and auxiliary equipment.

The brake equipment on these locomotives consists of the Westinghouse No. 8ET schedule with two 8 1/2-in. cross-compound compressors. The main reservoirs are cast as part of the engine bed and have a capacity of 55 000 cu. in. The braking ratio on the engine truck is 45 per cent, on the drivers 60 per cent, and on the trailer 43 per cent. The engine truck brakes are operated by two 10-in. by 8-in. cylinders, the driver brakes by two 16-in. by 10-in. cylinders and the trailer brakes by four 8-in. by 8-in. cylinders. The train-control equipment is the Union Switch and Signal two element type with three-indication cab sig-



Boiler cross-sections and elevation of the Milwaukee 4-6-4 locomotives



One of the boilers ready for the erecting floor.

nals. The locomotives are fitted with Valve Pilot speed recorders.

The air compressors are mounted under the streamline shrouding just back of the pilot. The air-compressor exhausts, together with the exhaust from the feedwater-heater pump, enter a header on the outside of the smoke-box which is connected to a tunnel on the inside of the smokebox. The upper end of this tunnel discharges into a cavity cast integral at the rear of the stack. The generator is on a cast-steel bracket back of No. 3 driver on the right side.

The generator and headlight equipment were furnished by the Pyle-National Company.

The main cab turret is just forward of the cab under the cowling. It is connected inside the boiler with two 3-in. pipes leading from the dome. Saturated steam from this turret is supplied to the flue blowers, cab heaters, stokers, injectors, water conditioner and steam heat. Superheated steam is supplied to the whistle, air pumps and generator from a separate turret.

The cab is of the vestibule type, of welded copper-bearing steel, wood lined and insulated with Hairinsul. A recess in the exterior of the cab sides provides a toe hold for passing from the cab to the running board. Steam radiators have been installed on both sides of the cab and in the gangway. There are two seats, with Spongex cushions, on either side and drop seats are mounted on the rear vestibule wall on both right and left sides.

The metal cab-window sash were supplied by the O. M. Edwards Company and have shatter-proof glass in all sash.

On the front of these locomotives is a Buckeye type E folding coupler with a 6-in. by 8-in. shank. The Franklin Type E2 radial buffer is installed with the Unit Safety drawbar. Barco flexible connections are used between the engine and tender.

Lubrication.

Mechanical lubricators supply the force-feed oil lubrication. A Nathan DV5 26-pint lubricator on the right side distributes oil to the valves and cylinders as well as the stoker and air pumps. A five-feed lubricator of 24 pints' capacity on the left side distributes oil to the driving boxes and guides. Three of the locomotives in this order have Detroit lubricators on the left side and the other three have Chicago lubricators. Both lubricators are driven from connections at the top of the combination levers.

Pressure grease lubrication is used extensively. Altogether 236 Alemite fittings are used on the engine and tender. The engine truck has 27 fittings, the cross-

heads, guides, motion work and reverse gear 42 fittings, the trailer truck 21 fittings, and the tender truck 58 fittings. Additional fittings on lubricator drives, valve-stem and crosshead guides, throttle rigging, motion, side rods and crank pins, spring and brake rigging, and wheels and boxes total 74 fittings. Rex fittings are used at 12 points on the driving boxes.

Streamlining.

The streamlining on this locomotive follows the general theme of the first Hiawatha locomotive as far as the front end is concerned, which is at an angle of 16 deg. to the vertical. Every effort was made to adapt the form of the shrouding to established structural lines.

The front of the streamline shrouding opens at the center line on concealed hinges, giving access to the smokebox front, whistle and air-horn mountings. The air pumps are on either side of the front end behind the pilot skirting and are accessible through hinged side panels in front of each cylinder. A removable panel gives access to the hinged-type coupler. There is a grille above the headlight in front of the whistle and horn. This grille is made up of flat rolled-steel bars with the narrow edge to the front trimmed with Snapon stainless steel molding. These metal-trimmed bars are arranged in such a manner that the headlight remains the focal point of the front « face » of the locomotive. The original Hiawatha wing ornament has been retained in a somewhat modified form. This ornament is of stainless steel with a satin finish. The front hand rails are fitted to follow the lines of the headlight and wings and thereby become a part of the ornamentation. The road name is attached to the pilot skirting in stainless steel letters.

The pilot skirt is continued around the cylinders for aerodynamic and protective reasons and in order to accentuate the appearance of height and power rather than of width. The ornemental panel of the side cylinder skirting is continued forward so as to be visible from the front. In order further to relieve the appearance of bulkiness, the pilot skirting merges to a point at the bottom.

While the predominating color of the front end is gray, the horizontal striping of maroon and Milwaukee orange yellow as applied to the skirting below the running board has been continued around to the front in the same manner as the black-and-metal-striped panel on the cylinder skirting. On the bottom of the pilot skirt a maroon design breaks up the appearance of width by following the front edge of the striped cylinder panel. In addition to the ornamental value, the colorful appearance of the front of the locomotive has a decided safety value inasmuch as it is possible to observe it at great distances.

The cowling of the stack, sandbox and dome ends in a fishtail shape on the cab. The unbroken contour of this cowling contributes to smooth smoke flow and obviates the necessity of smoke deflectors. This cowling has been painted black. To retain a distinctive characteristic of the steam locomotive, a streamline cap has been shrouded around the stack and a smoke fin blended into the silhouette. The marker lamps are of special design. The stainless steel side hand rail runs back from the marker lamps and follows the contour of the boiler jacket and cab. Streamline brackets secure the hand rail in place. Between the top cowling and the running board the shrouding follows the boiler contour lines and is painted gray. The throttle arm, injector checks and flue blowers have not been covered.

The cab is a decided departure from conventional design. Every effort was made to increase visibility. This has been achieved by a narrow steel corner post permitting an increase in the clear width of the front cab windows. The

length of the cab is further emphasized by the use of aluminum sash with narrow horizontal mullions. By this means the glass area is greatly increased, providing a well-lighted cab interior. The vestibule cab door and window which furnishes unusual visibility follow streamline design of the sash.

Recognizing the public's interest in seeing the mechanism of the locomotive in action, the running gear has been exposed to full view by terminating the running board skirting above the tops of the drivers. The lower end of the running board drops down in a curve under the cab to the lower line of the tender and cars. Following the colors of the cars, the running board skirt has been painted in Milwaukee yellow with broad maroon skirts at the upper and lower edge. The wheels are painted gray with maroon rings around the ends of the axles on the hub, and the side, main and eccentric rods are highly polished with maroon in the channels. A chromium-plated builder's name plate is attached to the skirting at the cylinders and the name plate of the speed-line designer has been applied below the builder's plate in the black cylinder panel.

The tender treatment follows the color arrangement of maroon and yellow characteristic of the new 1938 passenger equipment.

The tender.

The tender tank is of all-welded construction and is built up on a Commonwealth water-bottom cast-steel underframe. The water capacity is 20 000 gallons and the coal space carries 25 tons. The hot well for the Wilson feed-water heater is on the left side behind the coal space.

The tender trucks are of the equalized six-wheel Commonwealth type with 38-in. Davis wheels and A. S. F. roller-bearing units. A. S. F. clasp brakes are used with 14-in. by 10 in. brake cylinders mounted inside on each truck. The braking ratio is 80 per cent.

The steam-heat connectors at the rear end of the tender are the Vapor flexible metallic type. The draft gear is the Miner velvet action passenger gear with Buckeye Type E coupler and yoke.

[385 (06 .111]

OFFICIAL INFORMATION

ISSUED BY THE

PERMANENT COMMISSION

OF THE

International Railway Congress Association

Enlarged Meeting of the Permanent Commission at Brussels (6th to 9th July, 1939.)

In compliance with a decision taken at its meeting on July 9th, 1938 (*), the Permanent Commission of the International Railway Congress Association held an enlarged Meeting (from July 6th to 9th, 1939) attended by most of the members of the Commission and in addition by a number of engineers and high officers of the large railway systems, specially invited to take part in the discussions on two questions of general and present interest : — Methods used to speed up passenger trains, with special reference to operation by means of railcars — Simplification of the working.

The proceedings of the Sectional Meetings and the Plenary Meeting will be published in an early number of this *Bulletin*.

The final summaries adopted by the Plenary Meeting held on July 9th, 1939, are reproduced hereafter.

QUESTION I.

Methods used to speed up passenger trains and the resulting expenditure. In particular, operating by means of railcars and the financial results obtained by this method.

SUMMARIES.

I. — The greatly increased speed of the passenger services during the last five years in most countries is the result of the general desire for faster travel, and competition from other methods of transport both on the main lines and on the secondary lines.

For the European Railways taken as a whole, during the last five years, the daily mileage covered at overall speeds of more than 96 km. (60 miles) an hour between two consecutive stops has increased more than fourfold (69 909 km. — 43 440 miles— in July, 1938, compar-

(*) See *Bulletin of the Railway Congress*, October 1938, pp. 1071-1072.

ed with about 14 557 km. — 9 045 miles — in January, 1934).

II. — Speeding up of passenger services in a large number of countries has been made possible by a radical change in traction conditions : electrification or use of railcars.

Very high running speeds can be reached with suitable stock with all forms of traction; however, electric motor coaches and railcars are particularly suitable for rapid acceleration. Consequently, they are of special value for fast services having frequent stops or numerous speed restrictions.

III. — When the traction conditions are not radically altered, it is possible to speed up the passenger trains considerably by :

(1) making the locomotives work harder or increasing their efficiency;

(2) reducing the weight of the trains;

(3) doing away with stops in certain stations, or shortening the stopping times.

During recent years, many Companies have increased the thermodynamic efficiency of their locomotives and streamlined the locomotives intended for fast services.

In addition, the present state of technical knowledge makes it posible to lighten the construction of metal coaches very considerably.

IV. — When the traffic is dense and there is a great difference between the speeds of the different classes of passenger and goods trains, the speeding up of the passenger trains may reduce the capacity of the line and considerably interfere with the other services. By the adaptation of the time-tables, these difficulties may be reduced. When the traffic is moderate or light, no difficulty is experienced.

V. — In order to speed up their trains, the Railways have generally had to attend to their lines :

— by increasing the superelevation and improving the entry to curves;

— by improving particular points requiring speed restrictions and reducing their number;

— by examining the structures;

— by improving the signalling;

— by correcting the level of the running road.

After the services have been speeded up, they must pay particular attention to the maintenance of the permanent way, particularly as light-weight rolling stock so far has shown itself very sensitive to imperfections in the track, especially at high speeds.

VI. — Whilst endeavouring to speed up the services, the Railways should bear in mind the importance of comfort; the passengers want faster, more frequent, and above all more comfortable services.

To assure the success of a new method of traction, by electric motor coach or railcar, it is very desirable that the rolling stock used be faultless from the point of view of smooth running and the damping out of noise and vibration.

VII. — In oder to please their passengers, many Managements have been led to increase the number of services as well as to speed them up.

This tendency has encouraged the extension of electrification and railcars in recent years, seeing that with these two methods of traction, the additional train-mile is cheaper than with steam traction.

VIII. — The use of single or double railcars has often given rise to serious

difficulties for the Operating Department, as regards meeting peak traffic in a satisfactory way, particularly on secondary lines.

Experience has shown that there exists a limit beyond which railcars are no longer suitable economically for periods of peak traffic. The possibility of coupling railcars to trailers, with or without driving posts, permits this limit to be raised noticeably.

In practice, for periods of exceptionally heavy traffic, it is necessary to utilise steam trains at least in some services. The use of steam traction in cases of this kind does not unduly increase costs if goods locomotives suitable for working passenger services can be used during these times.

The Managements using multiple-unit railcars, especially triple or quadruple railcars with 2nd or 3rd class compartments (Holland, Denmark) or second class only (Germany for express railcars) on the other hand find no difficulty in dealing with peak traffic, by coupling their multiple units together to form sets of 8 vehicles (Denmark) 9 vehicles (Germany) or even 12 vehicles (Holland), so that the capacity corresponds exactly to the traffic available.

IX. — *(a)* All other things being equal, the cost per mile of an electric train, apart from the initial cost of electrifying the lines, would only be about 70 % of that of a steam train of like capacity,

(b) The cost per mile for a four-wheeled railcar is about 30 % of that for a 3 or 4-coach steam train on secondary lines,

(c) The cost per mile for a bogie railcar of light design without trailer is about 60 % of that for the steam train on secondary lines.

(d) The cost per mile for a bogie railcar with a trailer is about 75 % of that for the steam train on secondary lines,

(e) The cost per mile for a high speed railcar is extremely variable, according to the type of stock and the operating conditions, but is less than that for a steam train of four bogie coaches for express services.

Generally speaking, the cost per seat available in a railcar is higher than that of the corresponding seat in a steam train.

In Holland, however, it has been found that the cost per seat available in the triplets, 2nd and 3rd class, is only about 90 % of that for a seat in the trains; three other Managements have reported similar findings in the case of other kinds of equipment.

X. — The cost of the railcar-mile per seat offered is high, on the one hand because of the maintenance costs, and on the other hand, because of the amortisation charges.

Maintenance costs are considerably reduced when the Railway owns a relatively large stock of railcars, strictly standardised from the mechanical point of view.

The amortisation charges can be reduced when the railcars are so built as to have a long life and give a very high annual mileage.

Experience already acquired would seem to show that apart from the motor portion of the car, the amortisation of modern railcars of robust type ought to be calculated on a period of at least 20 years, and an effective annual mileage of 87 000 (140 000 km.), corresponding to a daily mileage of 250 (400 km.) per railcar, of the whole stock.

XI. — The figures quoted above apply to expenditure on traction, i.e. about

60 % of the total cost of passenger services.

To complete this investigation, it would be necessary to put into figures the actual or possible effects of the different methods of traction on permanent way maintenance on the one hand and on operating as a whole, on the other hand.

As regards operating, for example, certain methods of traction should make it possible to obtain such economies as reduction in the number of classes, simplification of the rates, tickets no longer issued in stations but by train staff, etc.

It would be necessary to estimate the additional receipts with the different methods of traction, resulting from the higher train frequency or the speeding up of the services.

Finally, it would be necessary to estimate the advertising value of some of the services speeded up, which directly increase the railway receipts by an appreciable amount.

To sum up, it would be necessary to investigate not only the traction costs for one particular service, but the receipts and expenditure for a group of lines as a whole, taking into account the traffic lost to competitive methods of transport.

XII. — From a detailed investigation of the various costs of operation in relation to speed, carried out by the Reichsbahn, it is noted that certain expenses increase with the speed (locomotive maintenance and fuel consumption, permanent way maintenance), whilst other items decrease (train staff expenses, amortisation charges, etc.); for this reason the total cost of the train-mile reaches a certain minimum for an average speed of 80 km. (50 miles) an hour in the case of express trains.

In this way the Reichsbahn has been able to prove that the speeding up of its passenger services has made it possible to make appreciable savings, quite apart from any effects on the traffic, and that the speeds now practised (73.4 km. — 45.6 miles — an hour on the average for the express trains) could be further increased with advantage.

XIII. — The Managements who have speeded up and multiplied their passenger services, whilst assuring their comfort at high speeds, have in most cases been able to retain their traffic, and even been able to foster new traffic, in spite of road or air competition.

QUESTION II.

How should the problems of symplifying the working be considered, in the future, in the interest both of the public and of the railways?

SUMMARIES.

I. — The unfavourable financial position of most Railways, as a result, in particular, of ill-regulated competition between methods of transport, makes it especially necessary to find, in every field, simplified operating methods leading to savings.

Simplification measures may be the result of :

— either lightening of the legal obligations imposed on the Railways,

— or, within the frame of the legal obligations, a rational organisation of the working in order to bring it in line

with the actual requirements of the various services.

2. — In order to facilitate the investigations into the savings to be realised and to obtain from the public authorities some relief from the legal obligations, it appears interesting to classify the lines, according to the density and kind of traffic into « main lines » and « secondary lines », to which different operating methods should apply as a matter of principle.

In the case of certain lines or groups of lines, it proves interesting to draw up balance sheets clearly showing the cost prices and the deficit.

Main lines.

3. — Simplification of the working on main lines should be sought in the field of the fixed installations and the working conditions of the staff.

4. — A systematic revision of the buildings and tracks used for the operation may lead to some of them being dispensed with.

5. — The preponderating part played by staff expenses in railway budgets should call, as regards installations, for such solutions as might allow staff reductions to be made, viz. :

— equipping lines carrying heavy traffic with the automatic block;

— bringing all the point and signal operating mechanisms into a central signal box;

— equipping large marshalling yards on modern lines, in order to transfer thereto the work done in neighbouring stations;

reducing the expenditure on level crossing keepers;

— putting certain signal boxes or block signals out of service during periods when they are unnecessary.

6. — Particular value is attached to measures tending to proportion as exactly as possible the staff employed to the actual service requirements :

— by using auxiliary labour as standby staff;

— by temporarily transferring staff from one department to another;

— by contracting out certain work which does not affect the working safety (handling, cleaning).

7. — As regards stations of small importance, the question should be investigated as to whether they should still be served by rail, or are to be served by road, or again, whether they should preferably be closed for all or part of the traffic.

In such stations, economies can furthermore be obtained :

— by having the duties affecting the working safety and other duties carried out by the same men, or single man;

— by discontinuing all safety measures to be carried out by the station staff; the station can then be managed by a person not on the permanent staff, whose presence will be needed a few hours per day, the remaining duties being carried out by the staff of passing trains.

8. — It is generally possible to obtain considerable savings on the travelling staff.

The driving staff can be reduced to one man, particularly on electric locomotives or internal-combustion or explosion engines, provided such devices as the « dead-man » be used, or another employee can intervene in the case of incapacitation of the driver.

The train staff (conductor, guard) can

be reduced to one man, or even completely dispensed with in the case of short trains.

Duties affecting the safety are then carried out by the driving staff; such obligations should then be of a particularly simple kind, and it would be interesting to draw up the regulations accordingly.

Secondary lines of main line systems and secondary railways.

9. — Some Railways have found advantage in having some of their secondary lines worked by light railway Companies, whose staff is better used to simplified working methods than the staff of the main-line railways.

10. — Extreme simplification of the safety plant is possible on a secondary line, in particular the suppression of most of the signals and interlockings.

The regulations governing the operation of the line should also be simplified and adapted to the nature of the traffic and its density : the staff at all stations can be reduced as a consequence or even completely dispensed with, the responsibility as regards train running (meetings, overtaking) resting with the train staff, under the supervision of a single controller for the whole line.

11. — The rules in the matter of level crossing keeping can be relaxed :

— either by increasing the number of crossings without barriers,

— or by limiting the periods during which crossings are watched.

Such steps should not, however, result in unfavourable speeds of passenger trains.

General remark.

12. — The application of all the abovementioned simplification measures will relieve the budgets of railway undertakings, but will not be able to put an end to their unfavourable position if the Public Authorities do not endeavour to simplify in a general way the legislation on transport, in order to better adapt it to the requirements of the railways and obtain rational coordination of all methods of transport.

MISCELLANEOUS INFORMATION.

[621 132.5 (.43)]

1. — German State Railways' 2-8-2 superheated steam locomotive, Class 41, for express goods traffic.

(Die Lokomotive).

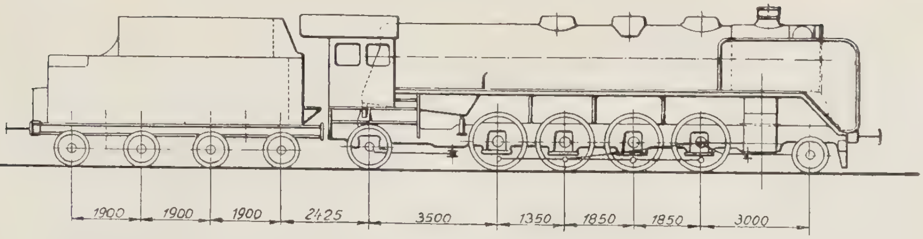
In May of last year, the first locomotive of a new class, No. 41, was delivered by the Berliner Maschinen A. G. (formerly L. Schwartzkopff). It was the first engine of the true *Mikado* type to be delivered to the Reichsbahn, and was designed first of all for express goods traffic working at an average speed of 90 km. (56 miles) p.h. With a maximum permissible axle-load of 17.5 t. (17.2 Engl. tons), it was decided to employ the boiler of the lighter 4-6-2 locomotive, class 03, with the difference that a pressure of 20 atm. (294 lb./sq. in.) instead of 14 atm. (206 lb./sq. in.) would be adopted, higher quality steel being used for the boiler plates.

The number of pairs of wheels being the same — in spite of the different wheel arrangement — an approximately equal weight is carried, perhaps somewhat higher, since the Krauss-Helmholz leading bogie is rather heavier than the small four wheeled bogie. With 20 atm. (294 lb./sq. in.) boiler pressure it has been found possible to provide cylinders of only 520 mm. (20 1/2 in.) diameter. With a piston stroke of 720 mm. (28 3/4 in.) the mean pressure being reckoned at 0.8 p., a maximum tractive effort of 19.8 t. (19.5 Engl. tons) or approximately 20 tons, is obtained, which, with an adhesive weight of 70-78 t. (68.9-76.8 Engl. tons), corresponds to a co-efficient of adhesion of 3.5 to 4. The total cylinder pressure, calculated as usual without piston rods, reaches 42.5 t. (41.8 Engl. tons), so that with a pressure of 14 atm. it would have been necessary to provide, as in the case of the 03 class, a cylinder diameter of 615 mm. (24 13/64 in.), which is practically the same as for the 610 mm. (24 in.) cylinders of the class 570, 4-6-0 engines of the Austrian Südbahn — whose other dimensions exceed those of the present *Mikado* engine — although its weight is 16 t. (15.7 Engl. tons) less. The boiler of the 03 class has, with a tube length of 6 800 mm. (22 ft. 3 5/16 in.), tubes of correspondingly large section, with the somewhat unusual dimensions of 162 × 171 mm. (6 25/64 in. × 6 3/4 in.) for the flue tubes, and 65 × 70 mm. (2 9/16 in. × 2 3/4 in.) for the small tubes. The deep firebox, which has inclined walls all round, has been provided with a well-designed ash pan which takes advantage of the long distance from centre to centre of the 4th pair of coupled wheels and trailing pair of wheels, which is 3 500 mm. (11 ft. 5 25/32 in.) as on the 03 class. The rear wheels diameter also remained unaltered at 1 250 mm. (4 ft. 1 13/64 in.).

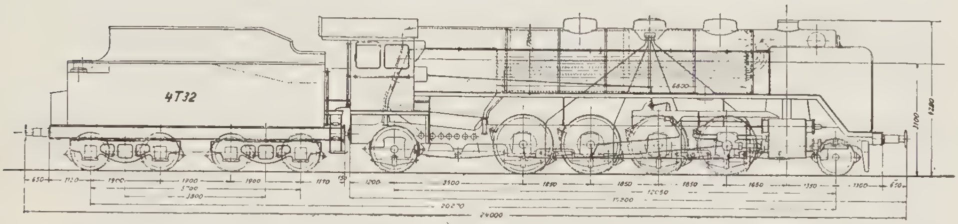
The forepart of the Krauss-Helmholz bogie is arranged in exactly the same way as a Bissel truck, with the same radial guides followed by centering coil-springs, but a certain amount of lateral play is given to the bogie centre pin, which is provided, in the usual way, with coupled laminated centering springs, 900 mm. (2 ft. 11 1/2 in.) long.

The 100 mm. (3 15/16 in.) thick bar frames give an interior spacing of 1 m. (3 ft. 3 3/8 in.) : as with all 12-wheeled locomotives each three sets are connected by equalisers, and all suspension springs, with the exception of those on the leading axle, are mounted under the axle boxes.

The motion, with unusually long coupling rods of 3 700 mm. (12 ft. 1 43/64 in.), necessitates large counterbalance weights, which come almost to the wheel centre. The suspension of the links and the arrangement of the reversing shaft have necessitated the provision of a long auxiliary frame from the cylinder to the middle of the wheels, which has robbed the bar frame of the advantages derived from its lightened-out design; the compressed air pump in the other set of six wheels has had to be catered for in the same way.



SCHWARTZKOPFF



2-8-2 (Mikado) type superheated express goods locomotive, class 41, built by the Berliner-Maschinenbau A. G. (formerly L. Schwartzkopff).

Engine:

Cylinder diameter	520 mm. (1' 8 1/2")
Piston stroke	720 mm. (2' 4 3/8")
Wheel diameter:	
Coupled	1 600 mm. (5' 3")
Leading	1 000 mm. (3' 3 3/8")
Trailing	1 250 mm. (4' 1 13/64")
Wheelbase:	
Leading wheels	3 000 mm. (9' 10 1/8")
Coupled	5 550 mm. (18' 2' 33/64")
Trailing	3 500 mm. (11' 5 25/32")
Total	12 050 mm. (39' 6 7/16")
Rigid	3 700 mm. (12' 1 43/64")
Boiler:	
Height of center line above rail head	3 100 mm. (10' 2")
Diameter	1 700 mm. (5' 7")
Tubes:	
Length between tube plates	6 800 mm. (22' 3 13/16")
20 flue tubes, diam.	162—171 mm. (6 25/64"—6 3/4")
84 small tubes, diam.	65—70 mm. (2 9/16"—2 3/4")
Heating surface:	
Tubes	202.2 m² (2 176 sq. ft.)
Superheating surface	70.0 m² (753 sq. ft.)
Combined heating surface	272.2 m² (2 929 sq. ft.)
Grate area	4.05 m² (43.6 sq. ft.)

Boiler capacity:	
Water	8.9 m³ (314 cu. ft.)
Steam	3.75 m³ (132 cu ft.)
Total	12.65 m³ (446 cu. ft.)
Evaporative surface	13.4 m² (144 sq. ft.)
Weight:	
Empty	92.6 t. (91.1 Engl. tons)
In working order	101.7 t. (100.1 Engl. tons)
Adhesive	70—78 t (68.9—76.8 Engl. tons)
Wheel loads:	
1st pair	11.21—15.38 t. (11.03—15.14 Engl. tons)
2nd pair	19.72—17.61 t. (19.41—17.33 Engl. tons)
3rd pair	19.67—17.54 t. (19.36—17.26 Engl. tons)
4th pair	19.18—17.48 t. (18.88—17.20 Engl. tons)
5th pair	19.21—17.26 t. (18.91—16.99 Engl. tons)
6th pair	12.69—16.47 t. (12.49—16.21 Engl. tons)
Overall length	15 200 mm. (49' 10 7/16")
Overall width	3 150 mm. (10' 4")
Highest permissible speed	90 km./h. (56 m.p.h.)
Maximum tractive effort, 80 % mean pressure	19.8 t. (19.5 Engl. tons)
Eight wheeled tender.	
Wheel diameter	1 000 mm. (3' 3 3/8 in.)
Wheelbase	5 700 mm. (18' 8 7/16")
Water capacity	32 t. (7 040 Br. gall.)
Coal	10 tons.
Weight:	
Empty	32.6 t. (32.1 Engl. tons)
In working order	74.6 t. (73.4 Engl. tons)
Locomotive and tender.	
Wheelbase	20 270 mm. (66' 6")
Length over buffers	24 000 mm. (78' 9")
Weight in working order	176.3 t. (173.5 Engl. tons)

Piston tail rods and automatic bye-pass valves are evidence of the attention which the Reichsbahn has devoted to the design. Both steam domes are so low that, in order not to exceed the maximum gauge (4 280 mm. = 14 ft. 1 1/2 in.) the normal fittings had to be fixed by means of special side flanges. On account of the increased working speeds, and the fact that goods vehicles are now fitted with the continuous brake, particular attention has been paid to the question of rapid and efficient braking, and all twelve wheels, including the front and rear carrying wheels, are braked by two shoes. Horizontal arrangement of the brake shoes could only be applied to the smaller wheels, and for the coupled wheels it has been necessary to arrange the brake blocks obliquely to avoid any increase in the distance between the coupled wheels.

The braking forces are well graduated, particularly in the case of the leading pair of wheels, which is less heavily braked, to avoid any possibility of the front wheels skidding and causing derailment, especially on sharp turnouts.

The sand boxes are located above the middle of the wheels, and operate in the forward direction only. A special Reichsbahn regulation requires that it must be possible, by modifying the arrangement of the extreme equalisers, to increase the weight on the coupled pairs of wheels from 17.5 to 19.5 tonnes, and so relieve the load on the front and rear wheels. These equalisers and their supports are provided with two holes, and by simply changing over the bolts concerned, the necessary alteration in the proportionate length of the equaliser arms is effected in a short time.

From the explanations given under the illustrations, it is fairly clear that the desired result has been obtained. For the complete utilisation of an axle-load of 20 tonnes on the coupled pairs of wheels, and approximately 18 tonnes on both end pairs of wheels, or a total weight in working order of 116 tonnes, an additional weight of 15 tonnes would have had to be provided by the use of the heavier boiler of the 02 class locomotive. As the behaviour of the locomotive, even up to 100 km./h. (62 m.p.h.), is quite satisfactory, and the power developed is equal to, or possibly somewhat higher than, that of the

03 class, it will be possible to use this class of engine with advantage, not only for high-speed goods traffic, but also for passenger trains, particularly for express passenger trains in hilly country.

As tables of loading are not available, the power of the locomotive will be computed in different ways. It must be at least equal to the 03 class, possibly somewhat more powerful at low speeds and less powerful at high speeds, always with the same pressure of 14 atm. (206 lb./sq. in.).

French experimental formulæ give the root of the increase in boiler pressure as increment value, which is 19 % in the present case, practically corresponding to the power of the heavy classes 01 and 02. The lowest critical speed at which the full adhesive weight can still be used is about 40 km./h. (25 m.p.h.), and the highest effective power would be developed at about 80 km./h. (50 m.p.h.), the speed of 90 km./h. (56 m.p.h.) being recommended only as an occasional limit, in accordance with the old empirical formula of half wheel-diameter.

For sustained power, with a minimum adhesive weight of 70 t. (68.9 Engl. tons) and a maximum of 78 t. (76.8 Engl. tons), the following figures may be given :

Gradient.	Load.		Speed.	
	Metr. tons.	Engl. tons.	Km./h.	M.p.h.
Level	900-1000	886-984	80-72	49.7-44.7
1 in 500	900-1000	886-984	68-62	42.3-38.5
1 in 200	900-1000	886-984	42-38	26.1-23.6
1 in 100	900-1000	886-984	25-22	15.5-13.7
1 in 70	450- 540	443-531	45-40	28.0-24.8
1 in 50	360- 400	354-394	45-40	28.0-24.8
1 in 40	300- 350	295-344	32-30	19.9-18.6

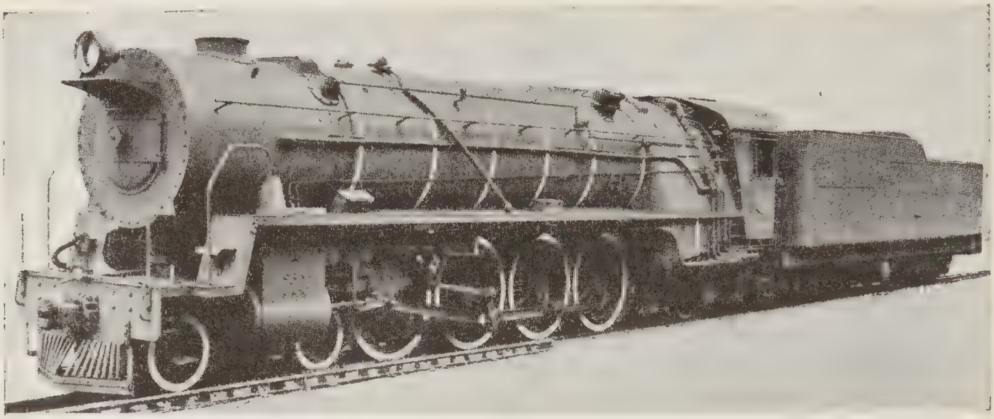
The last three values were obtained from experience with a 1 E locomotive, class 580, at Mursattel and Semmering.

[**621** 132.3 (.68) & **621**. 132.5 (.68)]

2. — New 4-8-2 type locomotives of classes 15 E, 15 F and 23, South African Railways.

(*The Railway Gazette.*)

The accompanying illustrations show three different classes of powerful 4-8-2 locomotives recently built for the railways of the Union of South Africa and known as Classes « 15E », « 15 F », and « 23 » respectively. The engines of Class « 15E » were constructed to the requirements of Mr. A. G. Watson, late Chief Mechanical Engineer, for working both passenger and freight trains over the main lines of the system. The Class « 15E » locomotives built at Darlington were illustrated and described in *The Railway Gazette* of January 10, 1936 (page 64). The Class « 15F » engines are in all main dimensions identical with « 15E » series, but are fitted with piston valves and Walschaerts motion in place of the R.C.



Class « 23 » locomotive with 5-ft. 3-in. driving wheels, piston valves and 12-wheeled tender. These engines have mechanical stokers.

poppet valve gear applied to earlier engines, and differ also in the arrangement of the flexible stays for the fireboxes.

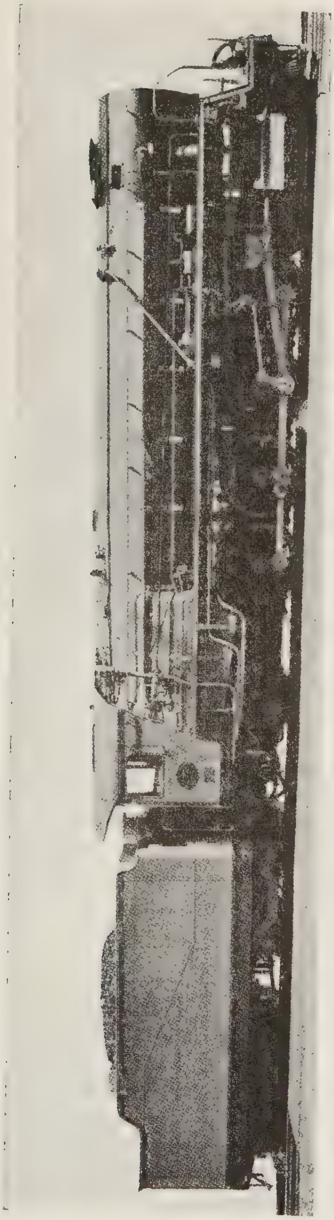
To meet the demands for a more powerful locomotive to handle the important passenger traffic over the main line between Cape Town and Johannesburg, the present Chief Mechanical Engineer, Mr. W. A. J. Day, designed the type of engine designated Class « 23 » in 1936.

In working out the designs for the « 15F » and « 23 » class engines, the question of the standardisation of as many details as possible has been kept in view. As a result the boilers of the « 15E », « 15F », and « 23 » classes are identical and the « 15E » and « 15F » are further, as already mentioned, practically identical in all principal dimensions, both engines being built on the same centres. The boilers common to these three classes are of large proportions, having a total evaporative heating surface of 3 414.5 sq. ft. made up as shown in the table hereafter. The superheater of 34 elements, 1 1/2 in. outside diameter, is of the short loop type and has a heating surface of 661 sq. ft., the flue tubes are 5 1/2 in. and the tubes 2 1/2 in. diameter. The length between the tube plates is 22 ft. 6 in. The inside firebox is of steel radially stayed, and two rows of flexible stays are fitted in the crown sheet at the front near the tube plate; flexible stays are also applied at the sides and in the back plate, in the so-called breaking zones.

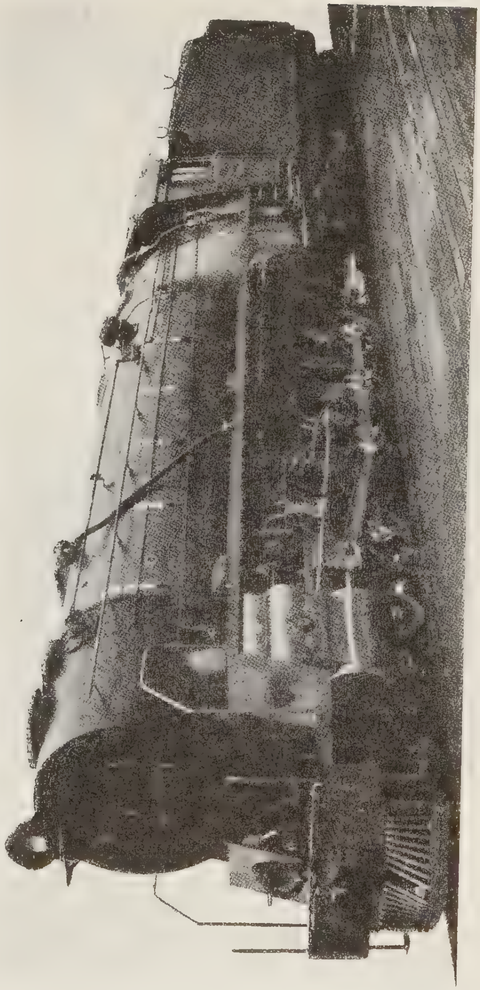
The main steam supply to the cylinders is taken through internal collecting piping to the superheater header, which incorporates a multiple valve throttle arranged on the saturated steam side in accordance with the South African Railways practice. The grate area is 62.5 sq. ft. and shaking grates are provided, as is also a hopper type ashpan with drenching piping supplied with water by the boiler feed injectors.

For the Classes « 15E » and 15F » engines, the working steam pressure is 210 lb. per sq. in. and for the Class « 23 » engine the pressure is 225 lb. per sq. in. Bar framing, machined from rolled steel slabs, is used for all the engines, each side being in one piece extending from the front bumper to the rear under the cab.

The boiler is carried at the back end by a vertical diaphragm plate and at the two front corners by sliding pieces resting on brackets fixed to the frames. The barrel section is further supported by flexible diaphragms at four points in its length, and the smokebox is bolted to the half saddles formed integrally with the two cylinder castings.



Above : Class «*15F*» locomotive with 5-ft. coupled wheels, piston valves and 8-wheeled tender.



Right : Class « *15E* » locomotive with 5-ft. coupled wheels, R.C. poppet valves and 8-wheeled tender.

The cylinders and details are interchangeable for « 15F » and « 23 » class engines. They are of cast iron and have liners; 12-in. dia., long-travel piston valves are used, operated by Walschaerts motion controlled by a steam reversing gear. Automatic air valves and Hendrie bye-pass valves are fitted, and a Sellar's drifting valve is used to supply steam to the valve chests when running with the main regulator closed.

Front view of class « 23 » locomotive.

The axleboxes for the coupled wheels are of bronze with Ajax grease collars. Ajax grease fittings are also supplied to the rods and motion, as well as to the brake gear and spring equalising gear. The return cranks have roller bearings, and the connecting rods and coupling rods have floating bushes. The crossheads, of steel castings, are of the underhung or Laird type, and the connecting rods are of heat-treated steel. The whole of the revolving weights are balanced and as large a percentage of the reciprocating parts as possible for the hammer blow at 55 miles per hour to be limited to 1.6 tons on any one wheel. The leading trailing and tender trucks have roller bearings, and both Timken and SKF types are being used. A steam brake operated by two steam cylinders acts on the brake blocks on each of the coupled wheels through the medium of compensated brake rigging. The axle loads are carried by overhung springs with compensating levers.

The leading truck is of a standard design, having swing links controlled by two horizontally placed laminated springs, and the weight is taken by the usual arrangement of laminated springs and compensating beams. The rear truck is of the Cole pattern with coil spring side-movement control gear.

The Class « 23 » locomotives differ principally from the others in having larger driving wheels, 5 ft. 3 in. as against 5 ft. Their use has necessarily increased the coupled wheelbase, and in order that these engines may negotiate the same curves as the other classes, the leading coupled axleboxes are allowed transverse movement, controlled by the Alco centring device, and the leading coupling rods have special bearings for the crank and knuckle pins to allow them to turn in their bearings.

The increased steam pressure of 225 lb. per sq. in. in the Class « 23 » engines produces the same tractive effort as for the engines of Classes « 15E » and « 15F », although the wheels are 3 in. greater in diameter. To enable these large locomotives to develop a high proportion of their potential power at running speeds, a mechanical stoker, of the H.T. type made by the Standard Stoker Company, is provided, thus permitting a larger amount of coal to be fired, and in that manner increasing the boiler output. The higher rate of evaporation has necessitated the provision of very large tenders, carried on 12 wheels, with a capacity of 18 tons of coal and 9 500 gallons of water. The engine of the mechanical stoker is also mounted on the tender. Four vacuum brake cylinders operate clasp brakes on each wheel, and in addition the usual hand brake is provided.

Principal dimensions.

The principal dimensions of the locomotives are as follow:

Type	4-8-2	4-8-2
Class	« 15E » and « 15F »	« 23 »
Cylinders, diameter and stroke	24 in. × 28 in.	24 in. × 28 in.
Wheels :		
Coupled	5 ft. 0 in.	5 ft. 3 in.
Front truck	2 ft. 6 in.	2 ft. 10 in.
Rear truck	2 ft. 10 in.	2 ft. 10 in.
Wheelbase :		
Coupled	15 ft. 9 in.	15 ft. 9 in.
Total engine	35 ft. 8 in.	36 ft. 0 1/2 in.
Evaporative heating surfaces :		
Tubes (136 × 2 1/2 O.D. × 11 S.W.G.)	2 014 sq. ft.	2 014 sq. ft.
Flues (36 × 5 1/2 O.D. × 3/4 in.)	1 165 sq. ft.	1 165 sq. ft.
Firebox (including arch tubes)	236 sq. ft.	236 sq. ft.
Total	3 415 sq. ft.	3 415 sq. ft.
Superheating surface	661 sq. ft.	661 sq. ft.
Combined heating surface	4 076 sq. ft.	4 076 sq. ft.
Fire grate area	62.5 sq. ft.	62.5 sq. ft.
Working pressure, lb. per sq. in.	210 lb.	225 lb.
Tractive effort at 75 per cent working pressure.	42 335 lb.	43 200 lb.
Adhesion weight	71 3/4 tons	73 3/4 tons
Weight of engine in working order	107 1/4 tons	111 1/2 tons
Water capacity of tenders	5 940 gal.	9 500 gal.
Coal capacity of tenders	12 tons	18 tons
Weight of tender, full	69 3/4 tons	105 tons
Total weight of engine and tender	177 tons	216 1/4 tons

NEW BOOKS AND PUBLICATIONS.

[385. (02]

The Universal Directory of Railway Officials and Railway Year Book, 1939-40. — London : The Directory Publishing Co., Ltd., 33, Tothill Street, Westminster, S. W. 1. 608 pp. 8 1/2 in. × 5 1/2 in. (Price : 20 sh. net.)

The Universal Directory of Railway Officials, originally issued in 1895, reaches with the present volume its forty-fith year of publication.

By fixing the date of issue in the middle of the year it has been found possible to include most of the operating and other figures for the year 1938, and thus give the volume the maximum currency with the latest annual information.

In the new edition opportunity has been taken to include additional Spanish railways and alterations arising from political changes in Central Europe.

The increasing development in the electrification of main-line steam railways has again necessitated revision of the tabulated information on this subject, and the table of the world's total railway mileage has been completely overhauled and amended from official replies to a questionnaire.

There are three indexes, namely : — (1) an index to countries; (2) a general index, including all reference to railways and statistical and other information; and (3) a personal index of railway officials.

The lists of railway officials have been brought up to date, together with brief description of the chief railway governmental and other authorities exercising control over railways.

[625. 1 (02]

Elsners Taschen-Jahrbuch für den bautechnischen Eisenbahndienst (*Elsner's Yearly Handbook for the Permanent Way Department*), 1939 (17th year). — One volume ($6\frac{1}{4} \times 4\frac{1}{4}$ inches) of 484 pages, copiously illustrated. — 1939, Berlin, Otto Elsner, Publisher. (Price, bound in cloth : 2.50 RM.)

The increasing popularity of our reference book in the last two years, says the publisher in his preface, is a sure proof of its usefulness.

There is no doubt that, from the point of view of the matters covered, it meets the requirements of the German permanent way experts, for whom it forms an invaluable guide in a concise form.

As is doubtless known, the main part of the book is a collection of the track laying diagrams used on the German railways, and in this edition the collection has been brought up to date to take the latest improvements in track equipment into account.

The tracks are shown by a single line, according to the usual practice on most railways, and the points and crossings by triangles marking the axes.

The collection also includes all the details for the laying of points and crossings with two lines per track, showing the metal sleepers or crossing supports.

German engineers are at present making an effort to standardise track equipment in order to make possible systematic renewal of the equipment and rational organisation of the maintenance.

There are very clearly dimensioned diagrams showing single and double turnouts, with spring or articulated blades, crossings, slip points, connections, cross-overs, turnouts in curves, on the inside or outside of the curve, as well as an extensive series of the most useful combinations of track equipment for drawing up layouts.

The 1939 edition also includes a chapter devoted to increased efficiency

of telephone lines by the use of multiple-frequency carrier currents.

This process makes it possible to use much less copper; the method is described at length, and illustrated, both as regards the equipment used, and the erection and wiring diagrams.

There is also a chapter dealing with the design and laying of telephone cables alongside electrified lines.

J. D.

[**621.** 13 (02 (.43). **621.** 138.5 (02 (.43) & **625.** 26 (02 (.43)]

Elsners Taschen-Jahrbuch für den Werkstätten- und Betriebsmaschinendienst bei der Deutschen Reichsbahn (*Elsner's Yearly Handbook for the Running Department and Rolling Stock Repair Shops of the German Reichsbahn*), 1939 (4th year). — One volume (6 1/4 × 4 1/4 inches) of 584 pages with many figures in the text. — 1939, Berlin, Otto Elsner, Publisher. (Price : 3.50 RM.)

In the June 1938 issue of the *Bulletin*, we mentioned the series of handbooks published by Messrs. Elsner, consisting of collections of the German Reichsbahn's instructions and regulations about the Running Department and Rolling Stock Repair Shops.

The first part of the new volume which has just been published in this collection gives first of all descriptions of the different types of compressed-air brake pumps and feed pumps for steam locomotives used on the Reichsbahn, as well as the regulations about the maintenance and repair of the feed water heaters. New repair methods are reported, such as the surface hardening of the crosshead guides by means of the oxyacetylene flame; building up flats in tyres, and flange wear of locomotive and tender wheels by electric welding; making good wagon tyre retaining rings by means of resistance welding, etc.

As regards the rolling stock, the Reichsbahn's organisation for sending passenger coaches, vans and mail coaches in for repairs and for putting them back into service after repairs is described; a description of the repairs to bogie vehicles with wooden bodies, such as the replacement of wood solebars by steel solebars; the instructions about the method of measuring up wagon frame parts in order to repair them to well defined tolerances, etc. Interesting sections deal with the question of detecting cracks in rolling stock parts, particularly in the axles, by the electro-magnetic process; the testing and periodical checking of pressure gauges; a description of a test bench for pneumatic drills and grinders, and the regulations about recovering scrap and spares, especially bolts and nuts.

The second part is devoted to questions connected with the operation of the running department : instructions about spare crews for steam locomotives, special regulations about the driving of locomotives with steel fireboxes, and the care to be given them; instructions about the driving and maintainance of high-speed locomotives; the use and maintenance of the Nicolaï pressure equalising piston valves; regulations about testing the lubricating oils and paraffin. In the chapter dealing with brakes, descriptions are given of the different types of driver's valves, that of the magnetic adhesion brake, etc.

The final part deals with the organisation of the accountancy, the organisation of the piece work in the repair shops, and the determination of the times for the different operations.

This new handbook therefore maintains the high standard of the previous volumes, and Running Department Engineers will find therein very complete information on many topical questions.

A. C.

[385 (093 (.497.2)]

The Fiftieth Anniversary of the Bulgarian State Railways (1888-1938). — A volume (8 1/4 × 11 1/4 inches) of 470 pages with inset map, and illustrations. — 1938 : Published by the General Management of the Bulgarian State Railways and Harbours, Sofia.

The first line of the Bulgarian State Railways was inaugurated on the 5th July, 1888. It ran from the Serbian frontier to Caribrod, Sofia, and Vakarel, and was 114 km. (70.8 miles) long. In actual fact Bulgarian railway history dates back much further than this. Before 1878, the year Bulgaria became an independent principality under the suzerainty of the Sultan, there were already several lines in operation, but in the very first years of the new State's existence the question of deciding the regime to be adopted for the railways came to the fore. In 1885 a law was passed instituting state ownership of the railways, and the first line to be built according to these principles was finished in 1888. Its inauguration must therefore be considered as the beginning of the Bulgarian State Railways, so that they celebrated their fiftieth anniversay in 1938.

The Management of the Bulgarian Railways published a beautiful book on the occasion to commemorate the work accomplished during this half century.

The authors have described the evolution of the railway system from the most diverse aspects.

First of all its development, which is the result both of the construction of new lines, and the buying up and reconditioning of existing lines, came up against serious technical and financial difficulties. The nature of the country made it an expensive matter to build the lines, and scarcity of capital was often combined with very hard conditions of purchase.

As regards the general rating policy, the thesis has generally been maintained that the public should profit by any reduction in cost obtained through various improvements, in order to encourage the growth of traffic by low rates and to enhance the economic part played by the railway.

The successive changes in the motive power and rolling stock are described; this is now so up-to-date that it can bear comparison with that of other formerly more favoured railway systems.

Other chapters are devoted to the fluctuations of the capital tied up in the railway system, its sources, and its relative importance; the recruiting, training, and remuneration of the staff; the frequency of the train services, and the gradual increase in the train speeds; the growth of the traffic, and variations in the kind of traffic carried; the structure and evolution of the rates; and finally the operating results and the financial results which have passed through varying fortunes.

Finally, a very interesting chapter clearly brings out the true value of the part played by the railway. It has been a preponderant factor in the development of agriculture and industry, it has encouraged the export trade, and improved the conditions of life of the greater part of the population. Special mention is made of the value of the railway from a strategic point of view.

The book is copiously illustrated with typical engravings, which have been very carefully selected.

The text of the laws in force affecting the railway is also given, and a fine map showing the present extent of the system.

E. M.

CORRIGENDUM.

BULLETIN for July, 1939.

Special report on Question I (Methods used to speed up passenger trains — Operating by means of railcars) by L. DUMAS.

(*a*) *Page 661 :* ITALY should be included in the table showing the countries working train services at speeds exceeding 70 miles (112 km.) an hour. A daily mileage of 251 (404 km.) is covered at over 70 miles an hour in Italy (*electric traction*).

(*b*) *Page 665,* 1st column, 20th line from the top :

Instead of :

The L. M. S. R. and L. N. E. R. are also using welded rails 36.50 m. (120 ft.) long...

Read :

The L. M. S. R. and L. N. E. R. are also using rails 36.50 (120 ft.) long as rolled...